A SHORELINE EROSION STUDY
OF THE ATLANTIC INTRACOASTAL WATERWAY OF GEORGIA,
CLASSIFICATION AND METHODS OF EROSION CONTROL

A THESIS

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A SHORELINE EROSION STUDY

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SUMMARY

The Atlantic Intracoastal Waterway (A.I.W.W.) of Georgia is bordered by approximately 370 km of shoreline. Erosion occurs along much of the Waterway as tidal scour and boat-generated waves persistently attack the shores. As development of estuarine shoreline property increases, the need for a better understanding of estuarine erosion and its control is apparent. To date, research on shoreline erosion within the vast estuarine system of Georgia has been limited.

A qualitative study was conducted on approximately 290 km of the A.I.W.W. of Georgia. The purpose of this study was to develop a systematic classification of shoreline erosion types prevailing on the A.I.W.W. of Georgia and to discuss mechanisms of erosion control. Investigations were limited to those portions of the Waterway located behind the protective barrier islands, excluding that portion of the route which passes through the sounds. Characteristic veatures produced by erosional processes were used to locate areas of active erosion and aided in the classification of shoreline types along the Waterway.

Field observations indicate that approximately 34 percent of the investigated shoreline is undergoing active erosion. It was also found that two types of shoreline exist: 1) grass marshes which are either eroding, accreting or stable, depending on their morphological status, and 2) sand and clay banks which are eroding and forming vertical,undercut faces.

A wide variety of erosion control structures are in use on the A.I.W.W. The most common commercial structures employed are treated wood bulkheads and stone revetments. The high cost of these structures often prohibit their use and alternative "home-made" devices are attempted, most of which were poorly designed and improperly constructed.

An alternative low cost erosion control system was installed on the A.I.W.W. and monitored from June 1977 to May 1978. The system consisted of three scrap tire revetment designs. Geotechnical examination of the surrounding marsh sediment was made on a regular basis to determine what effect the structures had on the marsh substrate and how effective they were in protecting an adjoining Pleistocene sand bank. Shear strength, water content, dry unit weight and size analysis of the sediments showed only slight variations throughout the study. The revetments had no apparent detrimental effect on the marsh substrate and presumably did not disrupt natural ecological processes. Further monitoring demonstrated that the three revetment designs tested successfully halted the erosion of the sand bank.

One section of revetment was fronted by a tire mat extending to the fringe of the <u>Spartina</u> marsh. Within three months following construction, the <u>Spartina</u> rapidly populated the tire mat and grew to heights nearly triple that of the grass anterior of the mat. Initial investigation of the sediment revealed increased levels of K and Mg within the tire mat.

CHAPTER I

INTRODUCTION

Statement of the Problem

The coastal region of Georgia contains one of the most extensive estuarine-marsh systems on the east coast. Erosion of the estuarine shoreline is prevalent throughout. Both short- and long-term effects of estuarine erosion need to be considered as development of the shoreline increases. To date, a variety of devices are employed to control erosion. This investigation was conducted as part of a study on the effective use of scrap-tires to minimize estuarine erosion.

The primary purposes of this study are to develop a systematic classification of the shoreline erosion types prevailing on the Atlantic Intracoastal Waterway (A.I.W.W.) of Georgia and to discuss mechanisms of erosion control.

Qualitative field reconnaissance of the A.I.W.W. enabled erosion site location and aided in type classification. Geotechnical analysis (i.e., shear strength, dry unit weight, water contents, and size analysis) provided the data base to determine the effect of three separate scrap-tire revetment designs on the marsh substrate.

The chronologic history and economic development of the A.I.W.W. of Georgia was presented in a detailed survey by Tinkler (1976). An environmental statement released by the U.S. Army Corps of Engineers (1976) investigated ecological parameters associated with the A.I.W.W.

Yapp et al. (1916), Yapp (1922) and Richards (1934) provided early information on the vertical and lateral development of a salt marsh in their studies of Dovey Estuary in Wales. Seasonal and environmental variations in sediment accretion of a Long Island salt marsh was examined by Richard (1978). Teal and Teal (1969) and Cooper (1974) described flora and fauna distributions within salt marsh regimes. Broome et al. (1973) and Terry et al. (1974) investigated nutrient characteristics of salt marsh soils in their attempts to construct salt marshes. Engineering and related physical properties adherent to a Georgia salt marsh were discussed by Pferd (1970). Johnson et al. (1970) adequately reviewed the geologic origin and subsequent development of Georgia's salt marshes.

The majority of shoreline studies have been concentrated on open coast environments. Recent problems of estuarine erosion in Virginia prompted shoreline studies by Givens (1976) and Byrne and Anderson (1977). Bellis et al. (1975) studied erosion in the estuaries of North Carolina. To date, a comprehensive study of estuarine shoreline erosion in Georgia is not available. Information supplied by this report is intended to form a base datum for future reference.

The Atlantic Intracoastal Waterway

The A.I.W.W. is an inland water route which extends from New Jersey to Florida. Control and maintenance is provided through the U.S. Army Corps of Engineers. Use of the Waterway is shared by pleasure boats and shallow draft commercial vessels.

Early improvements and alterations along Georgia's waterway commenced with an emerging shipping industry. Water cartage during the mid-1800's was an effective means to transport not only large quantities of freight and lumber, but passengers as well.

Initial surveys by the Corps of Engineers were site specific, prompted by requests from local shippers for safer, more direct routes. One of the first dredging operations was approved in 1882 for a cut to be made through Romerly Marsh (Fig. 1). An 1880 survey was the first to encompass the entire waterway from Savannah, Georgia to Fernandina, Florida and marks the actual beginning of the A.I.W.W. through Georgia. Improvement operations predominated until 1943 when periodic maintenance operations became the predominant activity. Today, the Corps of Engineers sustain a dredge program to maintain a navigable channel depth of 12 feet at MLW.

Scrap-Tire Revetments

The destructive effect of waves and high velocity currents on public and private real estate is apparent. While most inland waters have insufficient fetches to produce severe wind wave problems, boat-generated waves produce an almost continuous source of wave energy to estuarine shorelines (Soresen, 1967). Conventional means of maintaining channels and protecting eroding shorelines are very expensive. Costs of over $75 per linear foot for wooden bulkheads and $80-100 per linear foot for rock groins, revetments, etc. often prohibit their use by the private citizen.

The Goodyear Tire and Rubber Company, in conjunction with several research centers, has been experimenting with inexpensive,

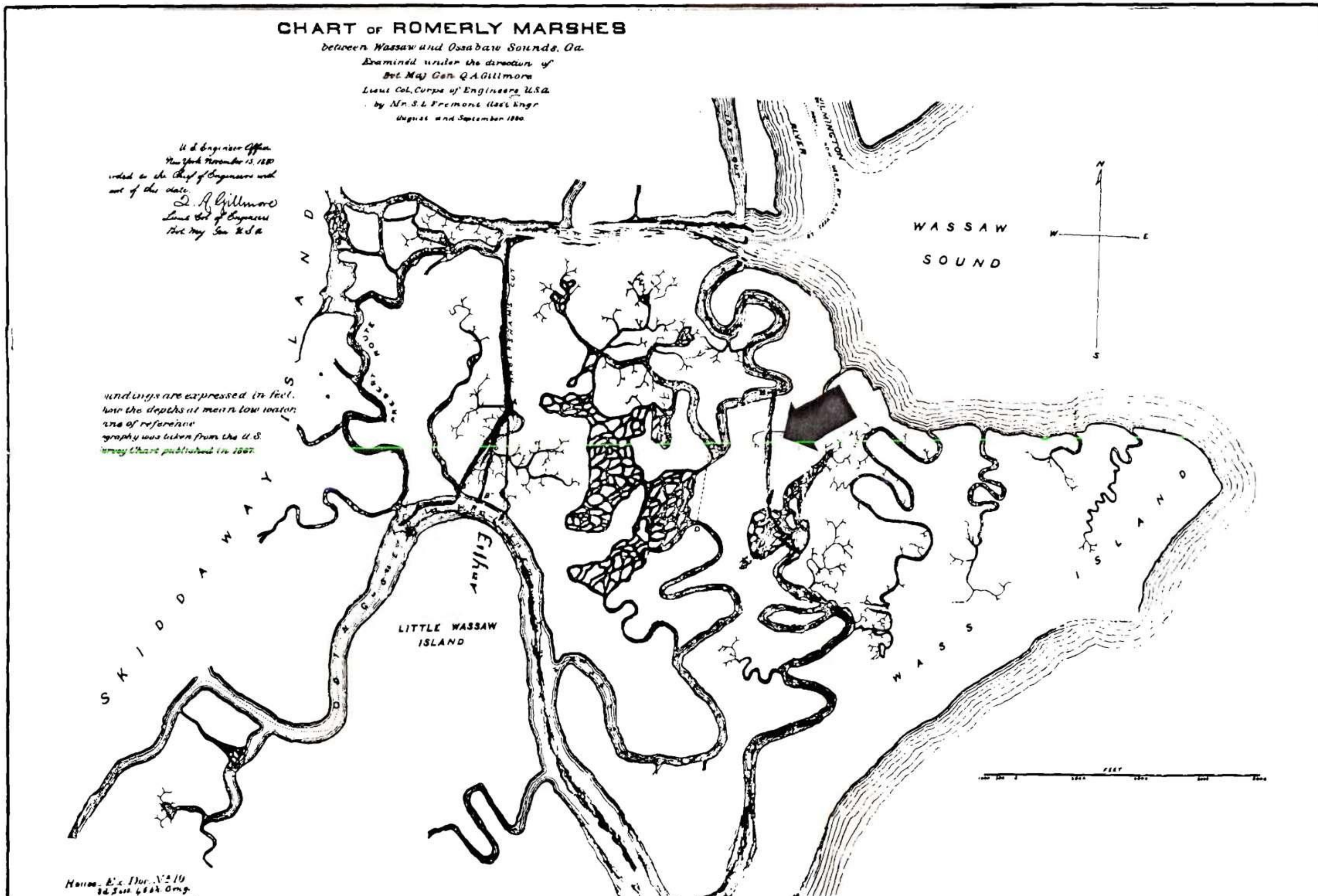

Figure 1. The Corps of Engineers 1882 Chart of Romerly Marsh Showing Location of the First Waterway Dredging

alternative methods for shore protection (Candle and Fischer, 1977). The basic building blocks are inexpensive scrap tires. Modules of scrap tires may be constructed into a variety of shapes and sizes to produce effective erosion control systems. Estimated costs of scrap-tire revetments range from $10-30 per linear foot.

In excess of 200 million scrap tires are discarded annually, an ample supply of inexpensive material for potentially large areas of shorelines adjacent to marinas, beaches, and waterways.

A scrap-tire revetment was constructed along a 90-meter section of eroding bank, adjacent to the Intracoastal Waterway. The site is located at the Skidaway Institute of Oceanography, Savannah, Georgia. Three construction designs were tested on the 90-meter section. Construction methods and applied use of the scrap-tire revetments are discussed in full by Oertel and Benoit (in prep.).

A vertical revetment consists of a seven-tire, vertically stacked module (Fig. 2). The inclined revetment is an eight-tire, tiered module (Fig. 3). Anchor material is 3/4" (SCH 80) PVC pipe which is fed through the tire centers and driven 3-4 feet into the substrate.

The third design is an inclined revetment with an attached mat (Fig. 4). The basic module is similar to the inclined revetment with the addition of a tire mat which extends forward into the marsh. One-quarter inch polypropylene rope was used to tie the tires together. Every sixth tire of the mat was anchored by driving a 4-foot length of PVC pipe through the tire center. The anchor rod and the tire were

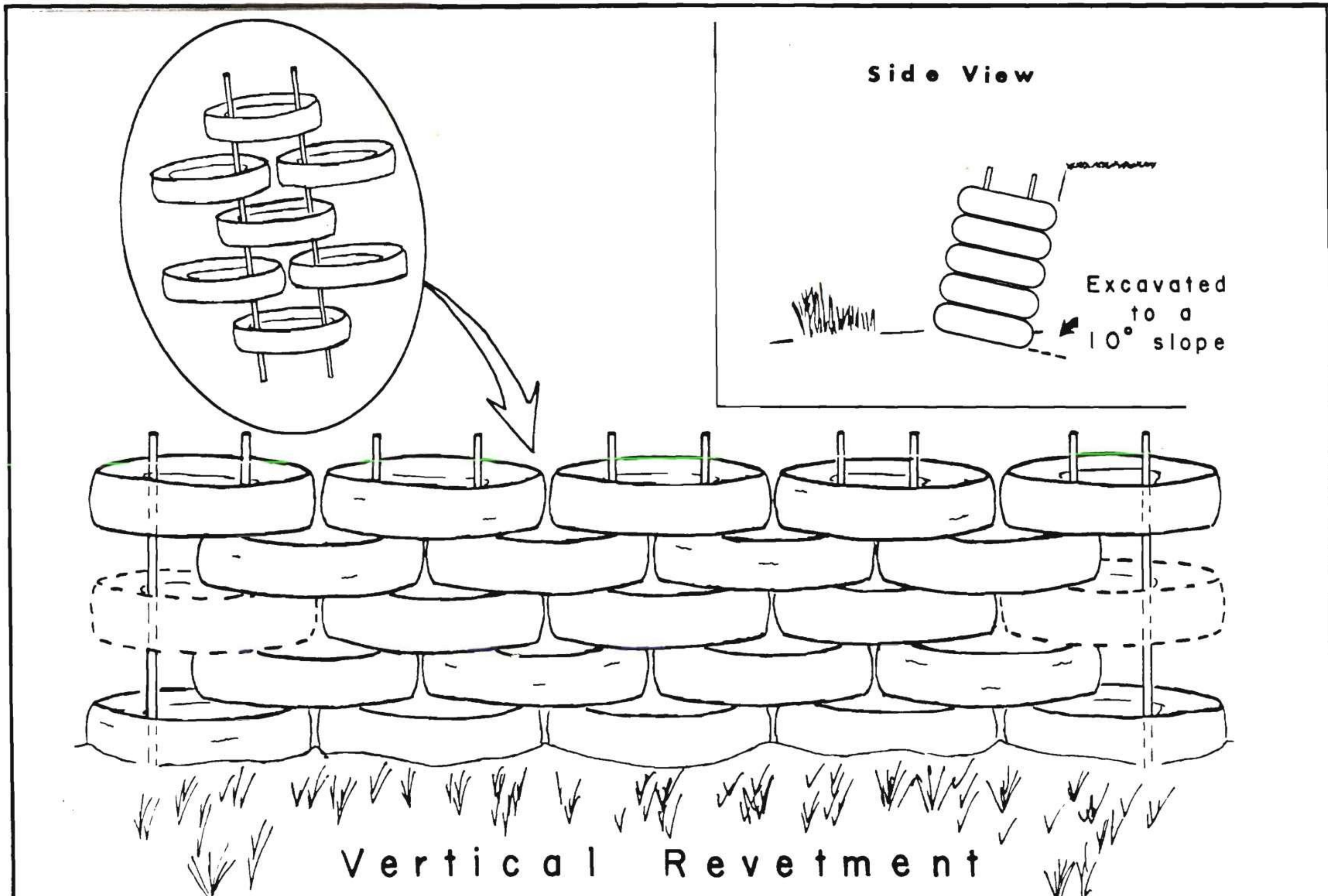

Figure 2. Design of the Vertical Revetment

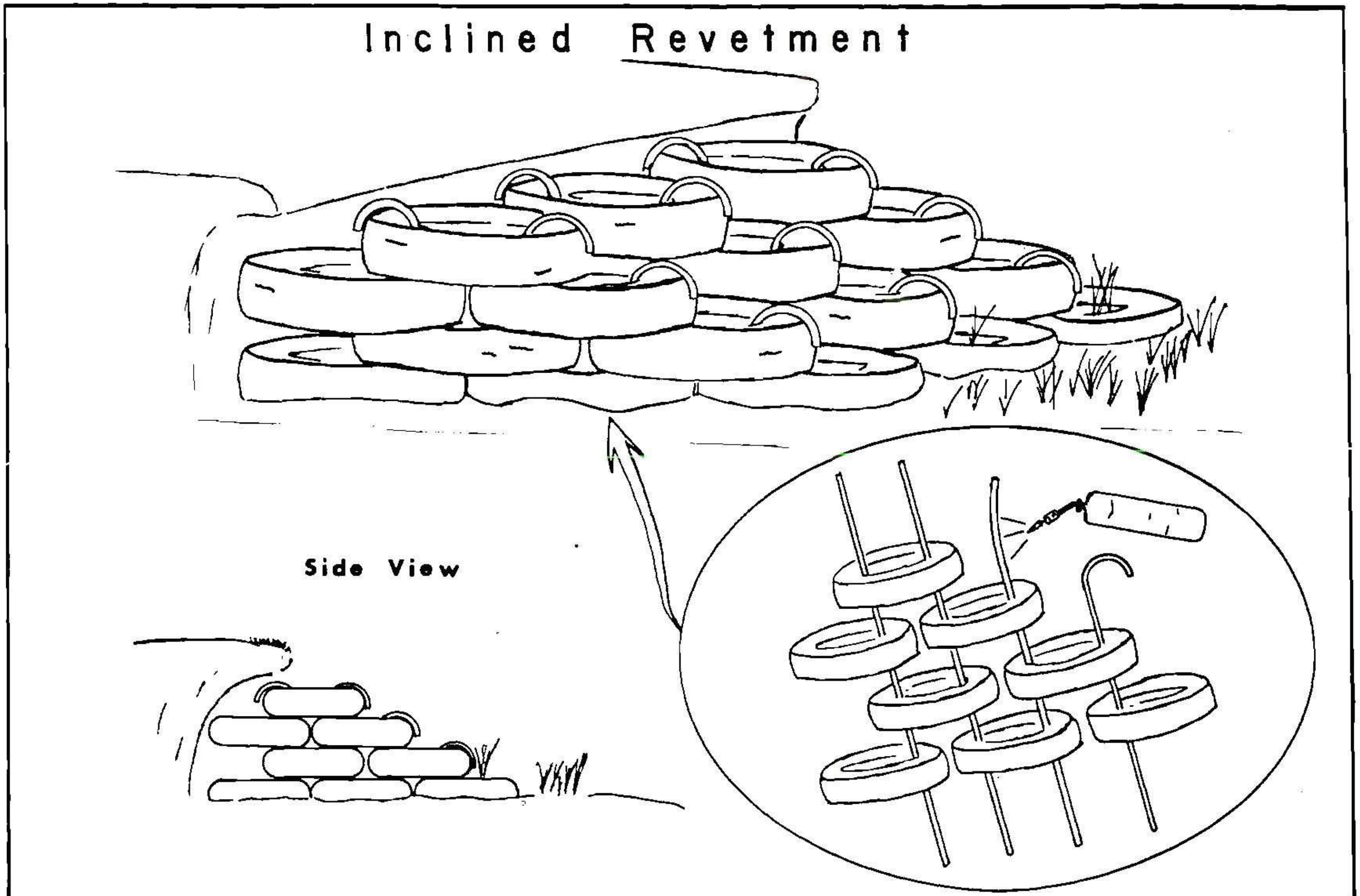

Figure 3. Design of the Inclined Revetment

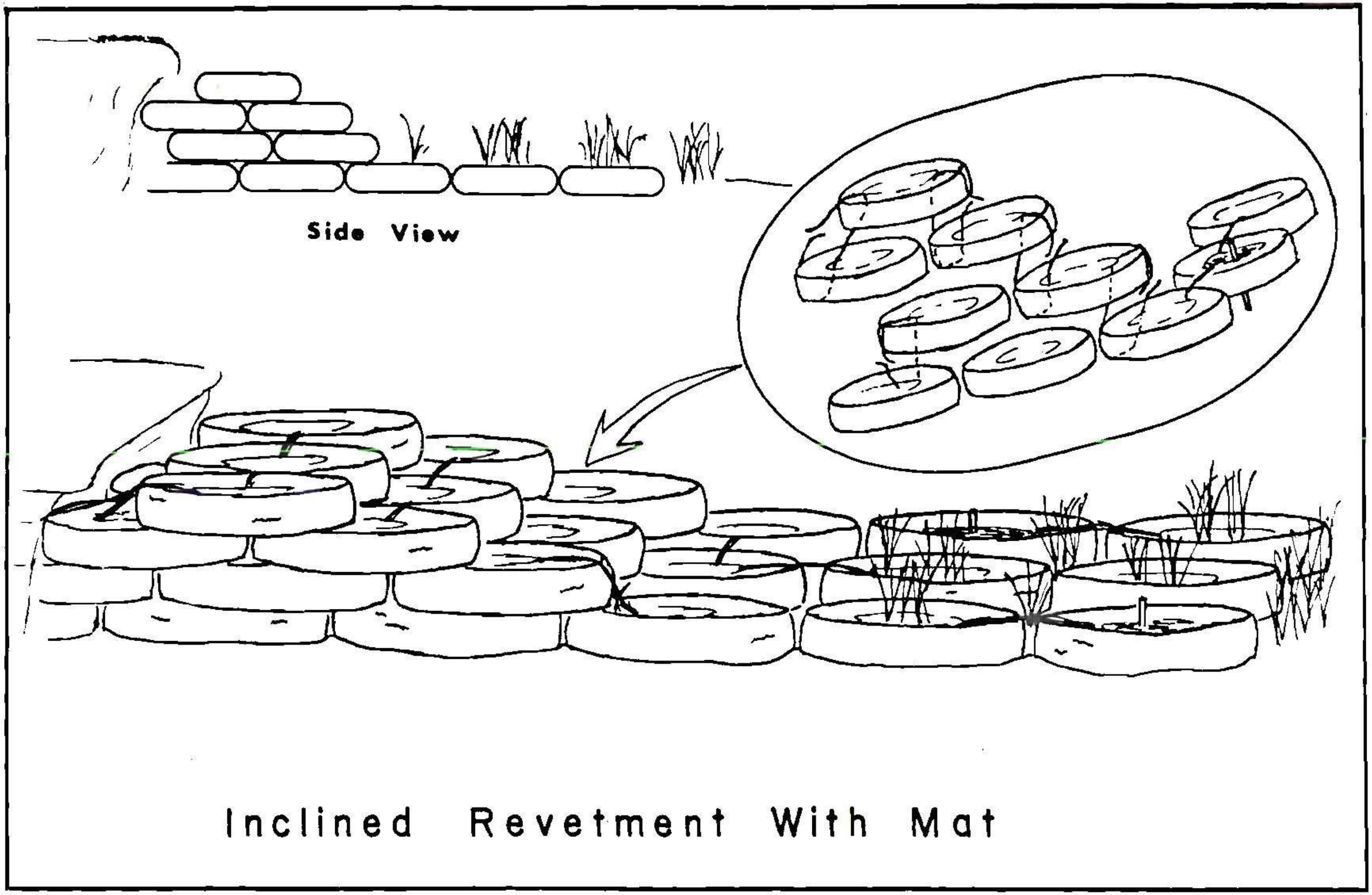

Figure 4. Design of the Inclined Revetment/Mat

permanently connected by filling the tire void with concrete. Engineering and geologic tests were used to monitor and analyze each design for effectiveness.

CHAPTER II

FIELD AND LABORATORY PROCEDURES

Site Descriptions

The study area of erosion site documentation is a reach of the A.I.W.W. situated within the Atlantic Coastal Plain physiographic province. Bounded on the north by the Savannah River, the Waterway extends southward 184 kilometers to St. Marys Entrance (Fig. 5). Approximately 370 kilometers of shoreline border the Georgia A.I.W.W. Nearly 393,000 acres of coastal marshland (Johnson et al., 1974, p. 68) surround the A.I.W.W. The dominant low marsh grass is Spartina alterniflora. Salicornia sp., Distichlis sp., Juncus sp. and Spartina patens occupy higher elevation marshes. Tides are semidiurnal with a range of 1.5 - 3.6 meters. Salinities are between 20-30 0/00 with fresh water input to the estuarine system provided by the Savannah, Ogeechee, Altamaha, Satilla, and St. Mary's Rivers. To the east, the marsh-estuary system is protected from open ocean attack by a series of Pleistocene-Holocene barrier islands. Each of the eight major barrier islands are separated by sounds, through which the A.I.W.W. passes (Fig. 5). Inlet and sound dynamics involve processes more complex than those reflected by inland water circulation (Oertel, 1972; 1974a). For this reason, the sounds and adjacent waters have been excluded from this study. The study area is restricted to main channels of the A.I.W.W. located behind the barrier islands. The total reach under investigation covers

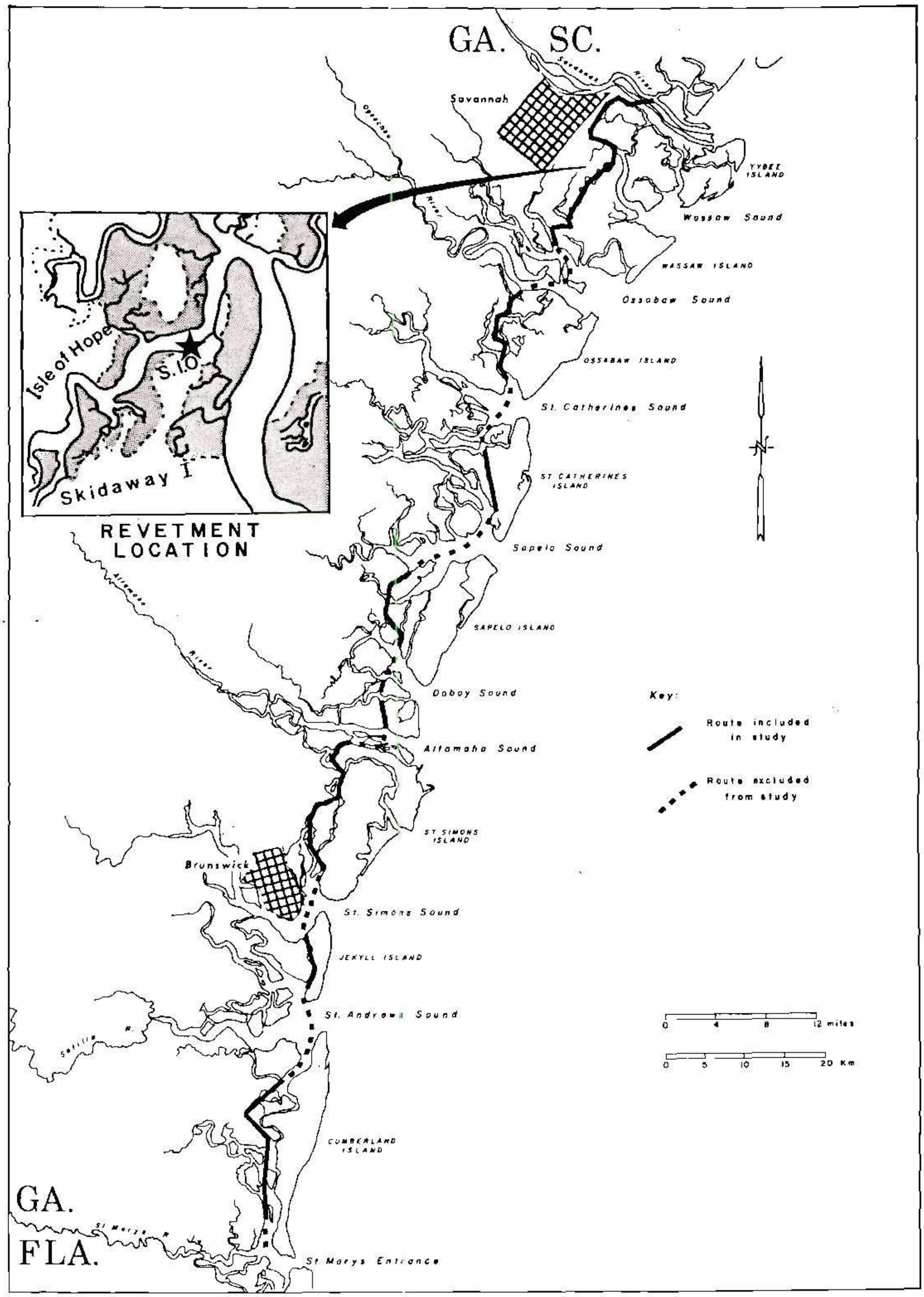

Figure 5. Location Map of the Scrap-tire Revetment Site and the Main Route of the A.I.W.W.

approximately 145 kilometers.

The scrap-tire revetment site selected for studying the effectiveness of the three designs is located on the Skidaway River (Fig. 5), directly behind the University of Georgia Marine Extension Center. Prior to installation, erosion occurred at the site at the rate of approximately one foot per year to produce a 1 - 2.5 meter high bluff. The bluff is composed of unconsolidated Pleistocene sand and intermittent clay lenses. Live oak trees (Quercus virginiana) exist atop the bluff. Although their root system partially protects the bluff, erosive energy is focused at the base, undercutting the face as much as 2 - 3 meters. When the supportive strength of the roots is lost, the trees topple over the bluff. As pointed out by Bellis et al. (1975), such large obstacles may act as "natural groins."

A narrow marsh (~10 meters wide) of predominately Spartina alterniflora is located in front of the bluff. The short Spartina-high marsh (Teal, 1958) consists of a clean, sandy substrate, most of which has washed out from the undercut bluff. The sediment increases in silt, clay, and organic matter rapidly as one approaches the marsh levee.

Six transects (A - F), two per revetment section, were established normal to the bluff face to monitor the interactions of the bluff, tires, and marsh (Fig. 6). The transects extend from the bluff edge to MLW. Four sampling stations were located along each transect. Station 1 is located midway up the bluff face. Station 1 was sampled only prior to installation to obtain a representative sample of the bluff soil. Since the objective of the study was to determine the effect of the tires on

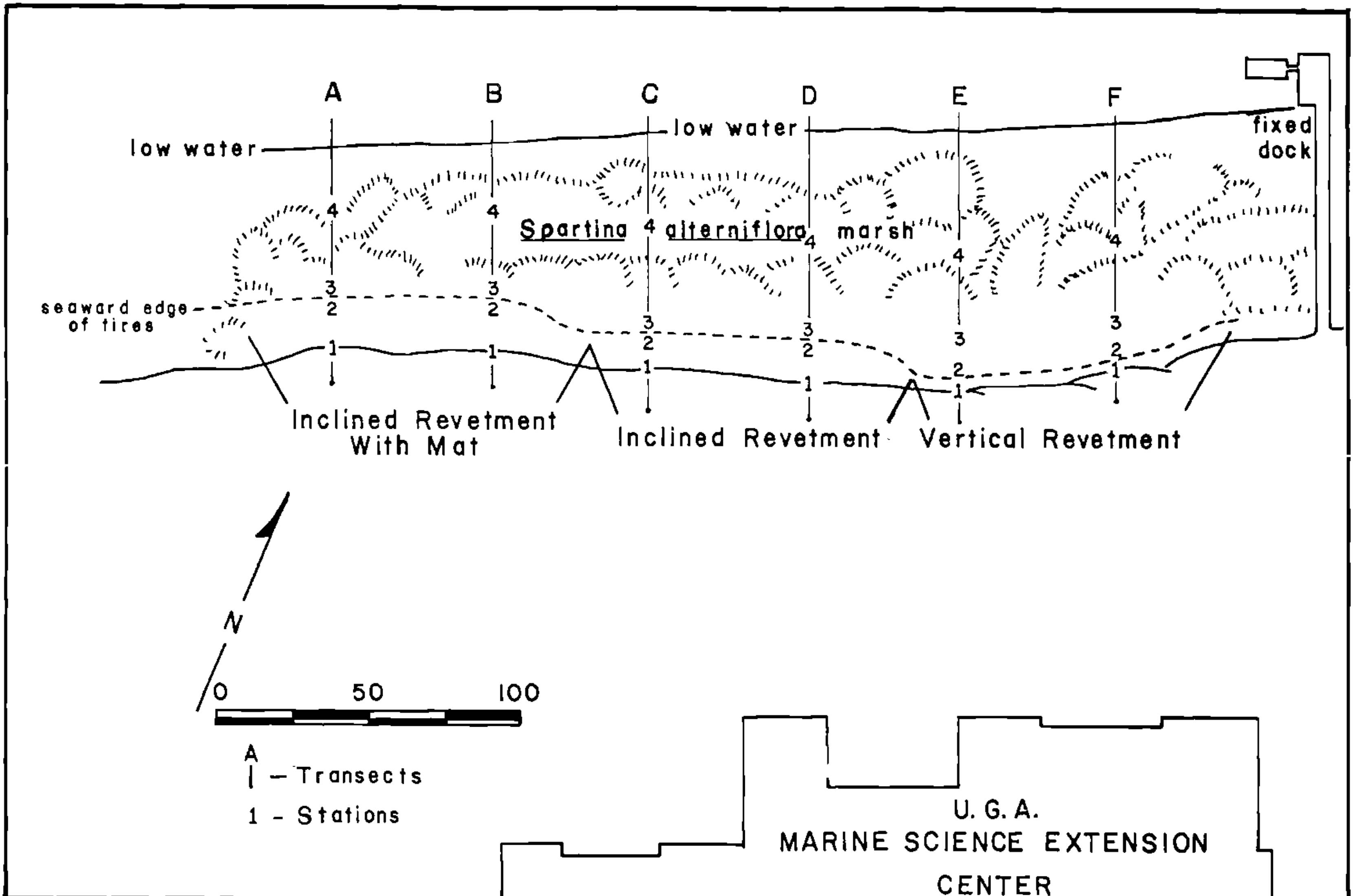

Figure 6. Location of Transects and Stations Within the Revetment Study Area

the substrate, stations 2, 3 and 4 were located relative to the position of the tires. Station 2 was located in the center of the outermost tires along each of the transects. Because the vertical revetment has no protruding tire to sample within, station 2 of transects E and F were situated at the base of the tires. The third station is 10 cm out from the base of the tires. Station 4 is 5 meters beyond station 3, and approximately in the center of the marsh terrace.

Procedures

Investigations of the A.I.W.W. utilized physical expressions of estuarine erosional processes. The following divisions of such expressions have been used as criteria in this study: .2 - .5 meter marsh scarp, .5 - 1 meter marsh scarp, sand bluffs, forest debris at the bluff base, and undercut banks. Areas of erosion were indicated on seven-and-a-half minute topographic quadrangle maps (scale 1:24,000). Field investigations were made during the one to two hours bracketing predicted low water.

As part of the monitoring program of the experimental revetments, photographs and elevation profiles were taken periodically. Shear strength, unit weight, and water content were recorded on a biweekly basis. Sampling commenced in September 1977 and continued through April 1978. Tests were conducted at stations 2, 3, and 4 of each transect. The average of triplicate runs for each parameter was taken as the representative value. In conducting investigations of the engineering properties of marsh soils on Sapelo Island, Georgia, Pferd (1970) removed the upper 50 cm of material to expose the underlying sediment.

Since this study is concerned with characteristics of the marsh surface, all tests were performed on undisturbed marsh. Attempts were made, however, to avoid major roots or dense vegetal mats that could have prejudiced the data.

Shear strength tests were performed in situ by a Soiltest Incorporated Torvane CL-600 shear device. The vanes were inserted into the sediment and torque applied until failure. The dial head is equipped with an indicator that advances to, and holds, the maximum reading.

To measure unit weight and water content, undisturbed samples were procured using a Soiltest Incorporated CH-940 Eley volumeter. This device allows extractions of accurate volumes. Samples were trimmed to 5 cubic centimeters, extruded, and placed in airtight containers. In the laboratory, the standard procedure of unit weight and water content determination was followed, as described by Sowers and Scholtes (1962).

Sediment used in size analysis was obtained monthly, from July 1977 to March 1978. At each transect, all stations were sampled in July 1977; however, only stations 2 and 3 were monitored thereafter. In order to have sediment representative of the surface layer, samples were obtained from the upper 2 cm. Yield per station was approximately 75 gm. Standard size analysis procedure by Folk (1966) was performed on 50 gm of the sample. Methods of sample preparation (i.e., removal of soluable salts and organic matter) are explained by Jackson (1956). The raw data was processed through a computer program that was derived by Slatt and Press (1976) to accommodate large quantities of size analysis data. Originally written for a Hewlett-Packard Model 9820A desk top calculator and plotter (Model 9862A), the program syntax was revised to run on a Hewlett-Packard Model 9825A desk top calculator. The program computes and plots statistical parameters and gravel-sand-silt-clay percentages and presents a graphic plot of a histogram, frequency, and cumulative curves (Fig. 7). The graphic plot of the repetitive samples of individual stations was too cumbersome to be in this report but are available upon request. Analysis of grain size data was made from the graphic plots.

As monitoring of the revetment site proceeded, a noticeable change occurred in the growth height of Spartina alterniflora. In attempts to determine the cause, examination of the marsh soil was initiated in November of 1977 and continued monthly until May of 1978. Samples were obtained from the upper 15 cm of stations A2, A3, and A4. The pH, percentage of organic matter, and evaluation of P, K, Ca, Mg, NO_3, and Na concentrations were performed by the Cooperative Extension Service, University of Georgia College of Agriculture

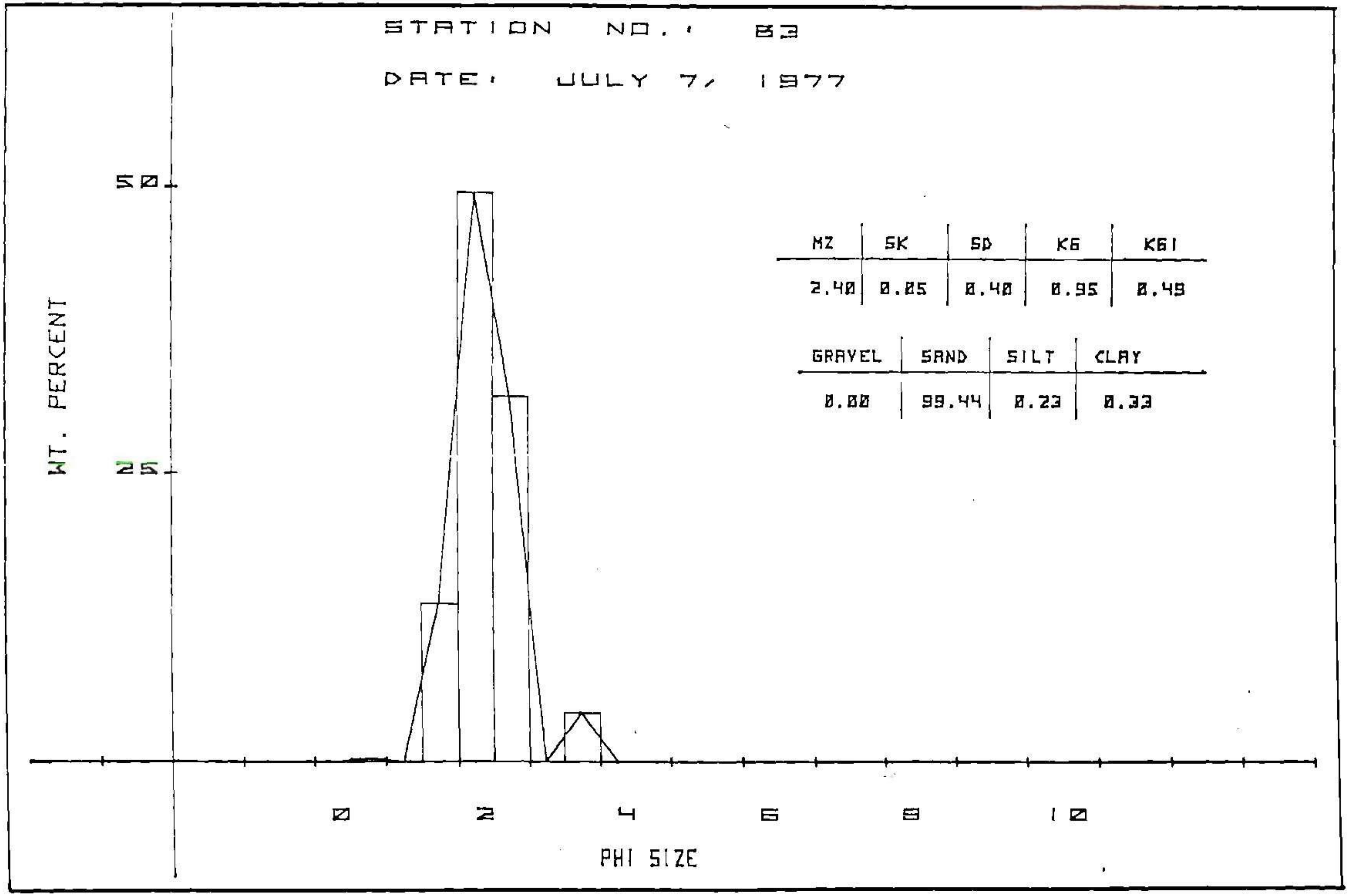

Figure 7. Example of a Hewlett-Packard Graphic Plot of Grain Size Data

CHAPTER III

RESULTS AND DISCUSSION OF RESULTS

Nomenclature

The majority of estuarine studies have been conducted by ecologists who were primarily concerned with the productive portion of the marsh. Their classification and subdivisions of marshes have been based on floral zonation (Teal, 1958; Cooper, 1974). Edwards and Frey (1977) used a classification based on marsh environment distributions. This classification is fully adequate until one expands the scope of study to include the estuary channels and banks. A sequence of descriptive terms has been compiled from the literature and is presented in a generalized cross-section of an estuary channel, marsh surface, and upland bank (Fig. 8). Descriptive terms are defined for use in this section:

Bank: The truncated, near vertical to undercut face of an elevated land surface.

Primary marsh terrace: An intertidal region of aquatic and grasslike vegetation. Subdivided by zonation of grasses and distribution of environments.

Marsh scarp: An erosional feature marking the retreating (channelward) edge of the primary marsh terrace.

Salt pan (barren): An unvegetated area within the primary marsh terrace of predominately sandy substrate (high

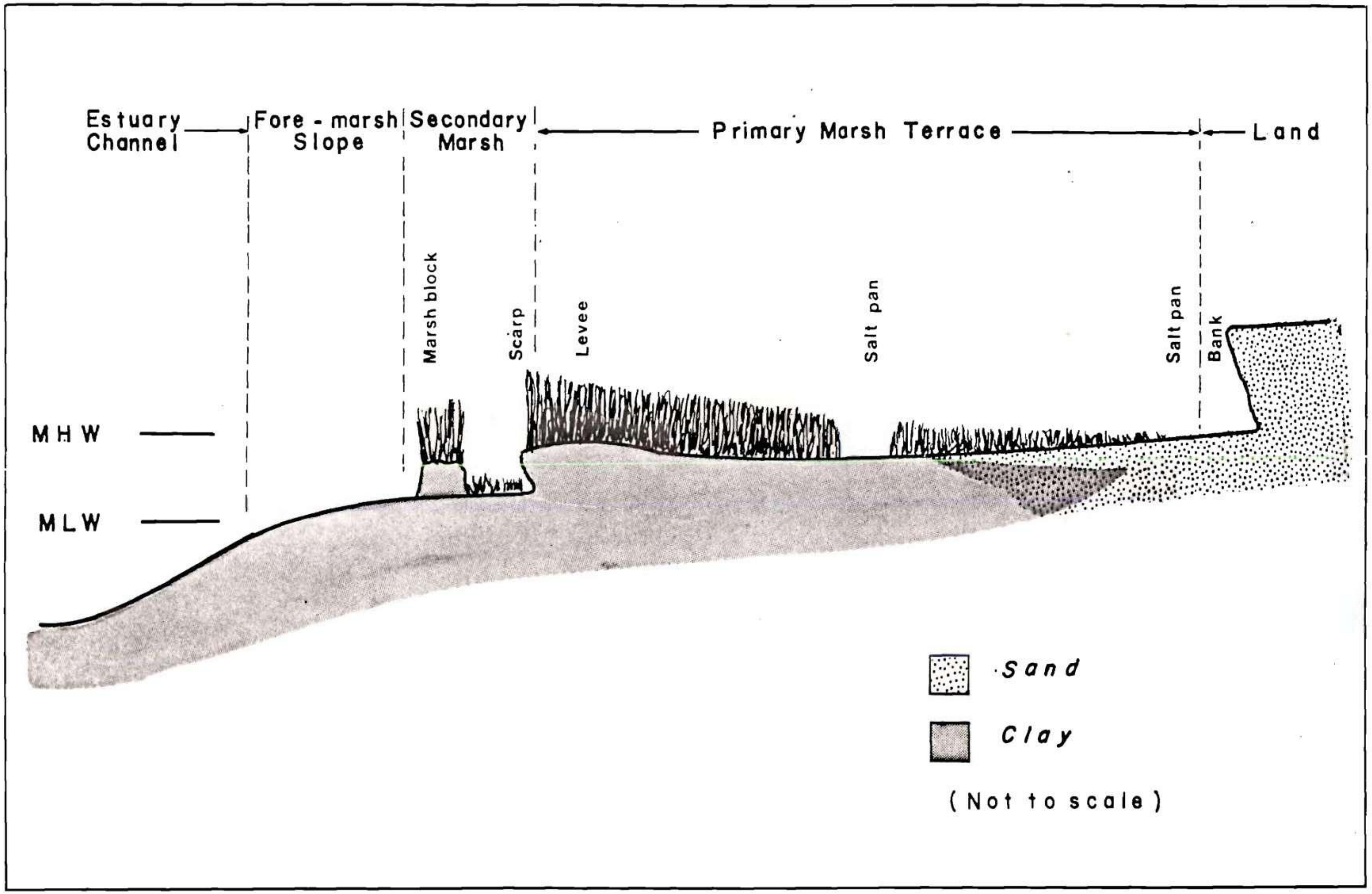

Figure 8. Cross-section and Related Nomenclature of an Estuary, Marsh and Land Surface

marsh) or muds (low marsh).

Levee: A raised depositional feature created by the accumulation of material just landward of the marsh scarp.

Secondary marsh: A fringe of new marsh along the landward margin of the fore-marsh slope, often created through rhizomteous development or re-establishment of marsh blocks.

Marsh block: A section of marsh detached from the primary marsh terrace through erosion.

Fore-marsh slope: An unvegetated, intertidal region, composed of soft mud and silts usually dissected by small drainage channels.

Estuary channel: A man-made or natural linear depression through which the main body of water flows. Identifiable by an abrupt change in the fore-marsh slope.

Shoreline Types and Classifications

The extent and nature of erosional features are summarized in Table 1. Percentages are based on occurrence within the study area and in several regions different features may coexist (Fig. 12). The dominant erosional feature was the .2 - .5 meter marsh scarp which comprised 76.3 percent of the affected region. Bank erosion occurred in 7.1 percent of the area. The .5 - 1 meter marsh scarp occurred less frequently and comprised approximately 4.9 percent of the 91 km. Fallen trees and forest debris littered approximately 10.2 percent of the eroding shoreline. Undercut shoreline was estimated to occur over 10 to 15 percent of the region. Nearly all marsh demonstrated a slightly

Table 1. Extent of Erosion Produced Features

Feature	Length of Shore-Line Affected (Km)	Occurrence Within the Eroding Portion of Shoreline* (%)
.2-.5m Marsh scarp	69.45	76.3
.5-1m Marsh scarp	4.45	4.9
Sand bank	6.45	7.1
Forest debris	9.24	10.2
Undercutting	9.1-13.7	10-15

*Several features may exist within the same region.

protruding root-mat at the leading (channelward) edge, and could thus be considered undercut. To minimize discrepancies, designations of undercut shores were restricted primarily to sand banks and those portions of marsh demonstrating obviously more severe undercutting than the immediately adjacent marsh.

Characteristic features of actively eroding shoreline locations are presented on 1:40,000 maps (Figs. 9 through 27). Estimates revealed erosion was prevalent along 91 km or approximately 31.4 percent of the total 290 km of Intracoastal shoreline. It has been shown (Meade, 1969) that bottom water in estuaries of the Atlantic Coastal Plain maintained a predominately landward flow and thus produced a net landward movement of sediment along the bottom. This process is apparently only active in estuaries that head in major rivers (Oertel, 1974b). Richard (1978) reported accretion rates on bare mud flats of 3.4 - 7.1 mm/yr. and on vegetated marsh of 2.0 - 4.25 mm/yr. Ranwell (1972) also reports reasonably high accretion rates on vegetated marsh (.2 - 1 cm/yr.). These results helped substantiate Wiedemann's (1972) conclusion that in natural salt-marsh estuaries, the process of sediment accretion dominates over erosion.

Alteration of the estuarine system by man burdens the natural balance of processes. Channel dredging and heavy boat traffic disrupt river hydrodynamics and the natural morphology of estuaries, leading to accelerated shoreline erosion. Dredging excavates deep channels that normally would not exist in the natural system. A comparison was made between the Corps of Engineers dredging location maps and the

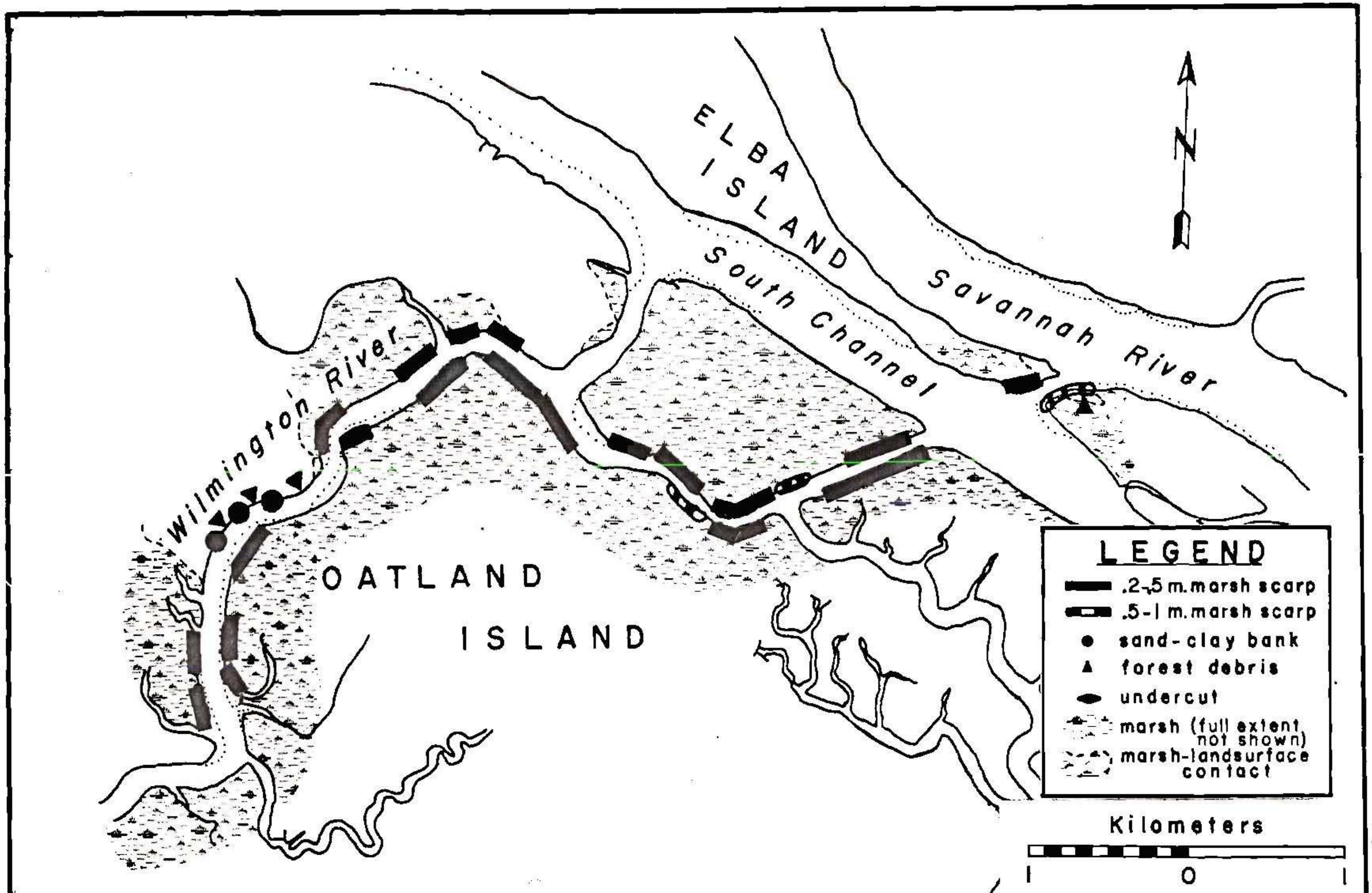

Figure 9. Erosion Site Locations; Savannah River to the Wilmington River

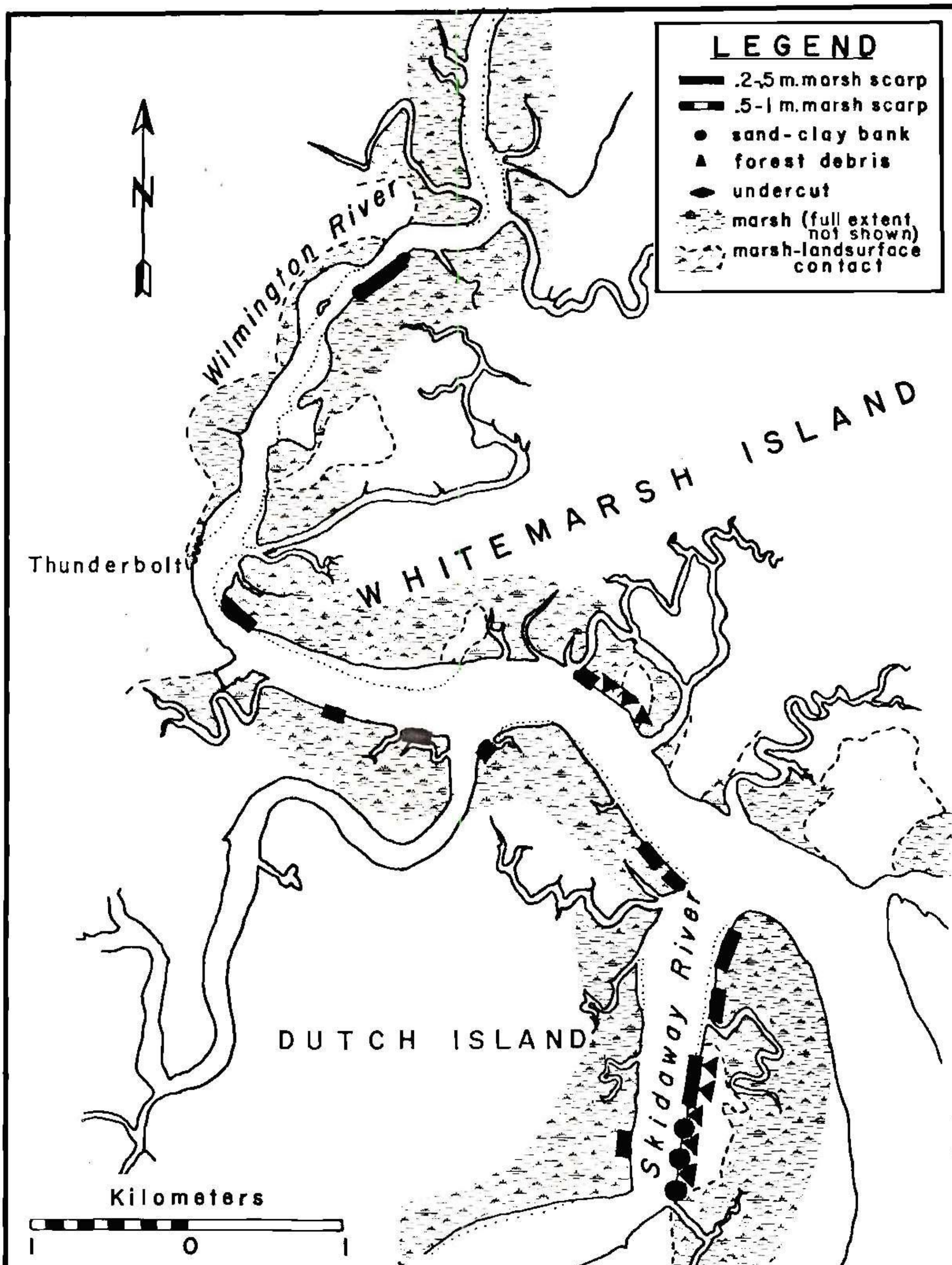

Figure 10. Erosion Site Locations; Wilmington River to the Skidaway River

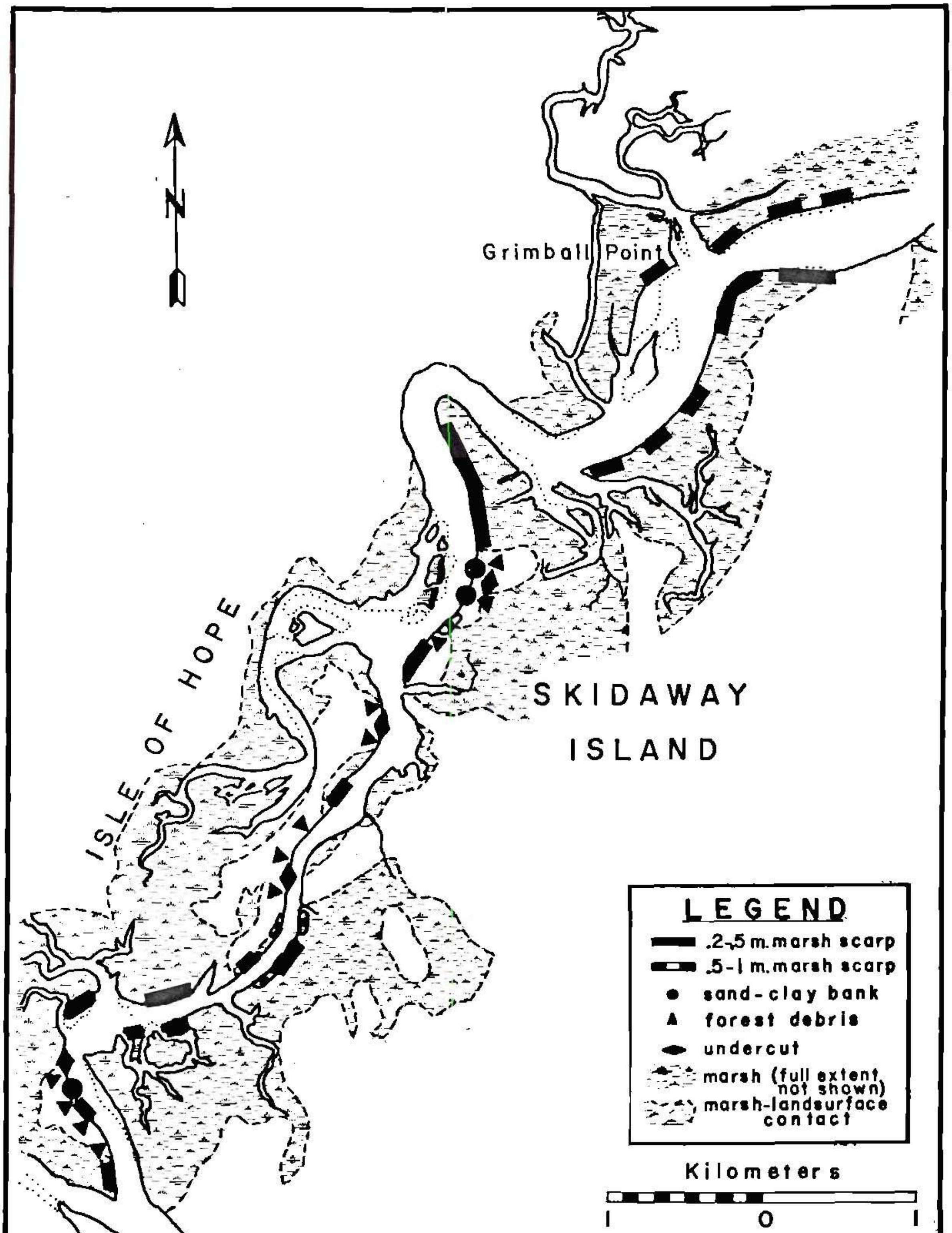

Figure 11. Erosion Site Locations; Skidaway River to Isle of Hope

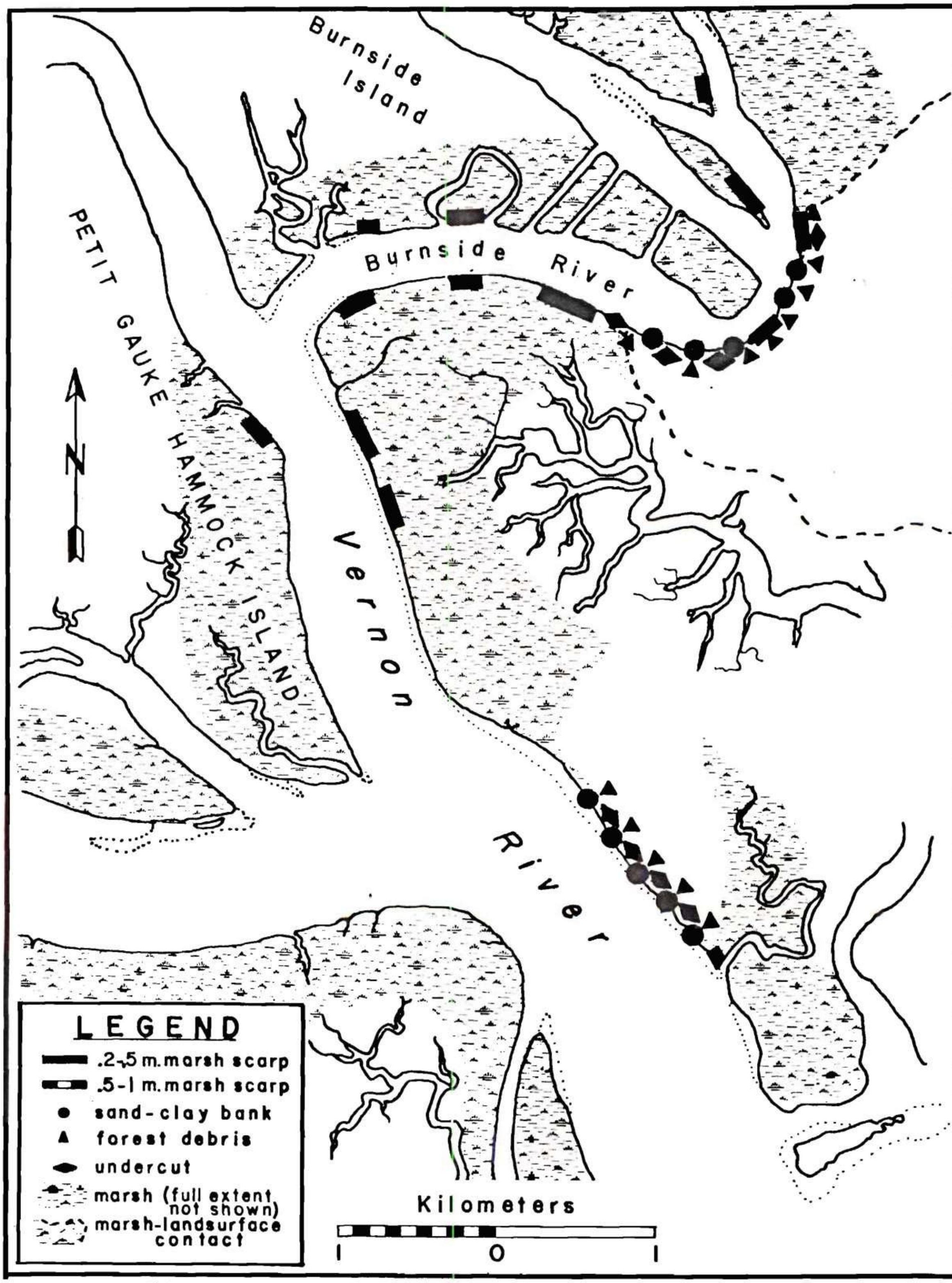

Figure 12. Erosion Site Locations; Isle of Hope to the Vernon River

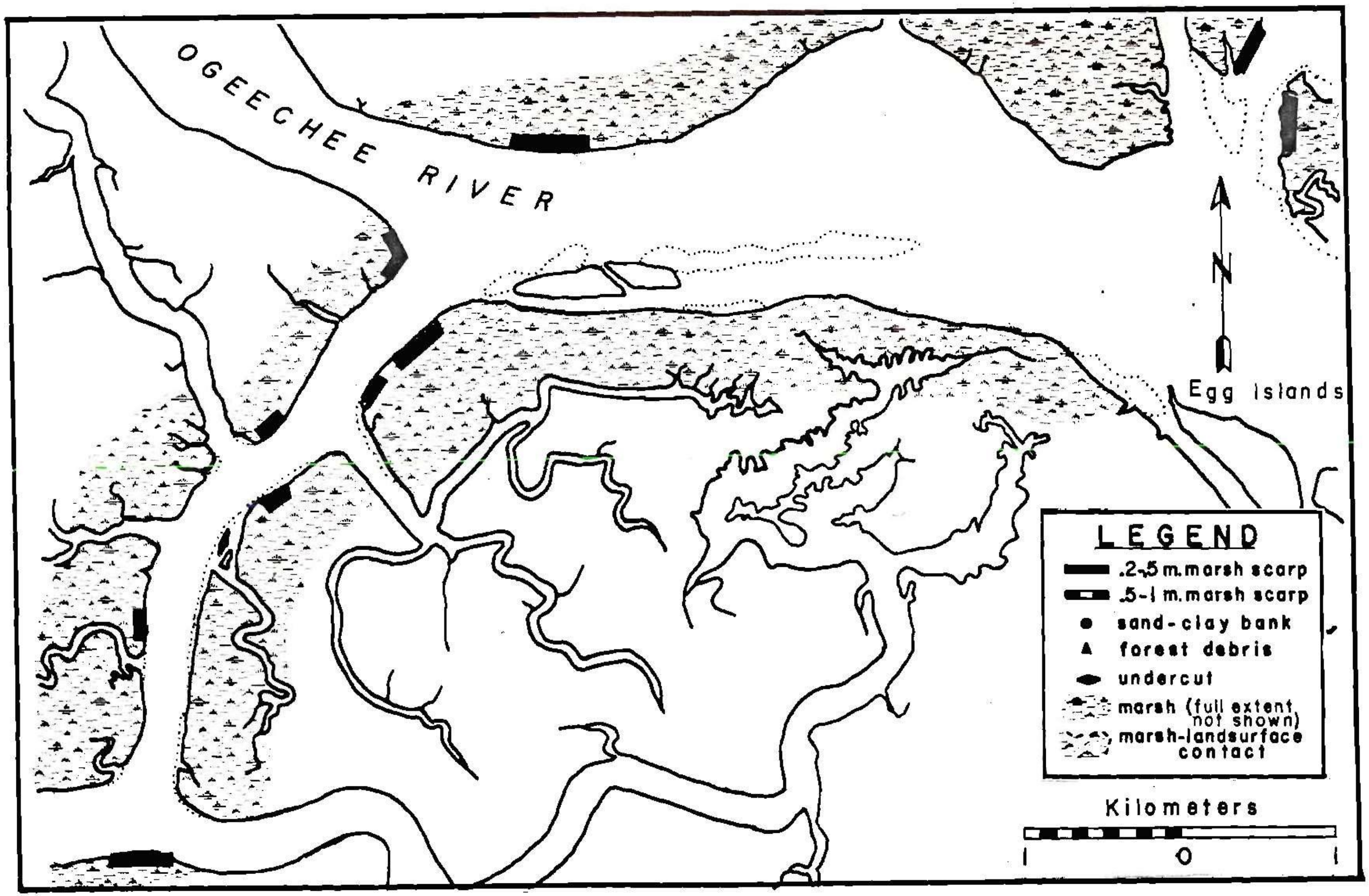

Figure 13. Erosion Site Locations; Hell's Gate to the Florida Passage

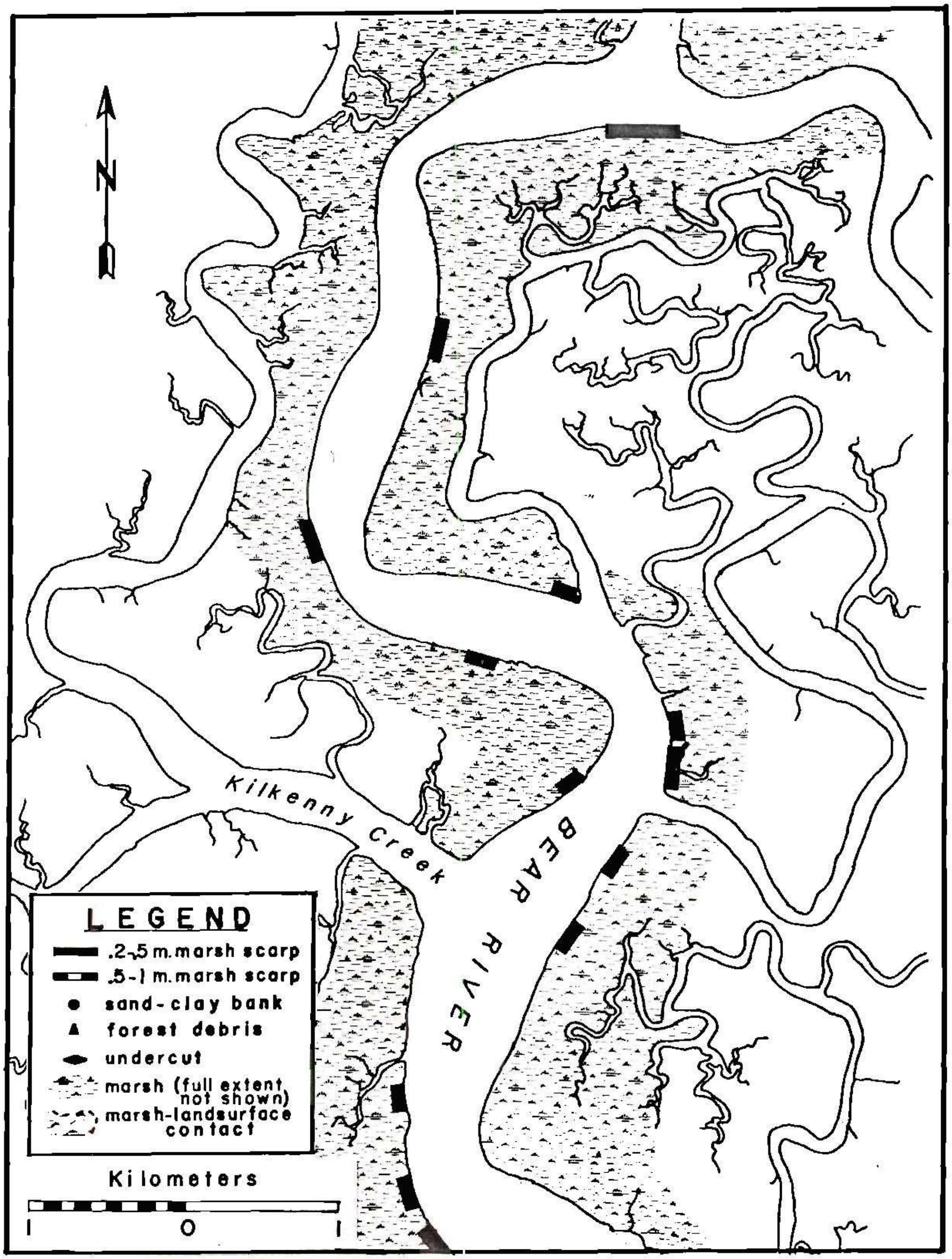

Figure 14. Erosion Site Locations; Florida Passage to the Bear River

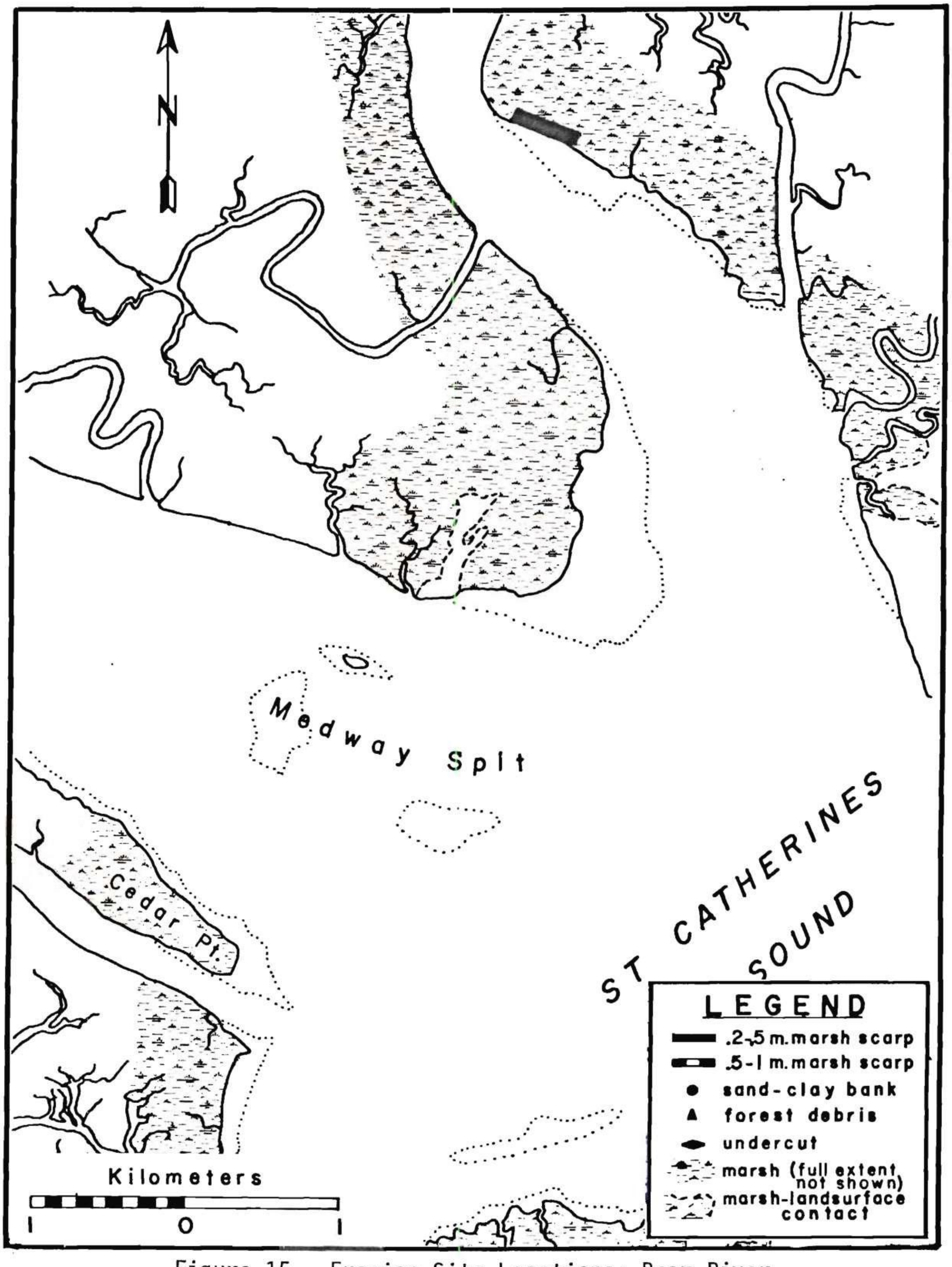

Figure 15. Erosion Site Locations; Bear River to St. Catherines Sound

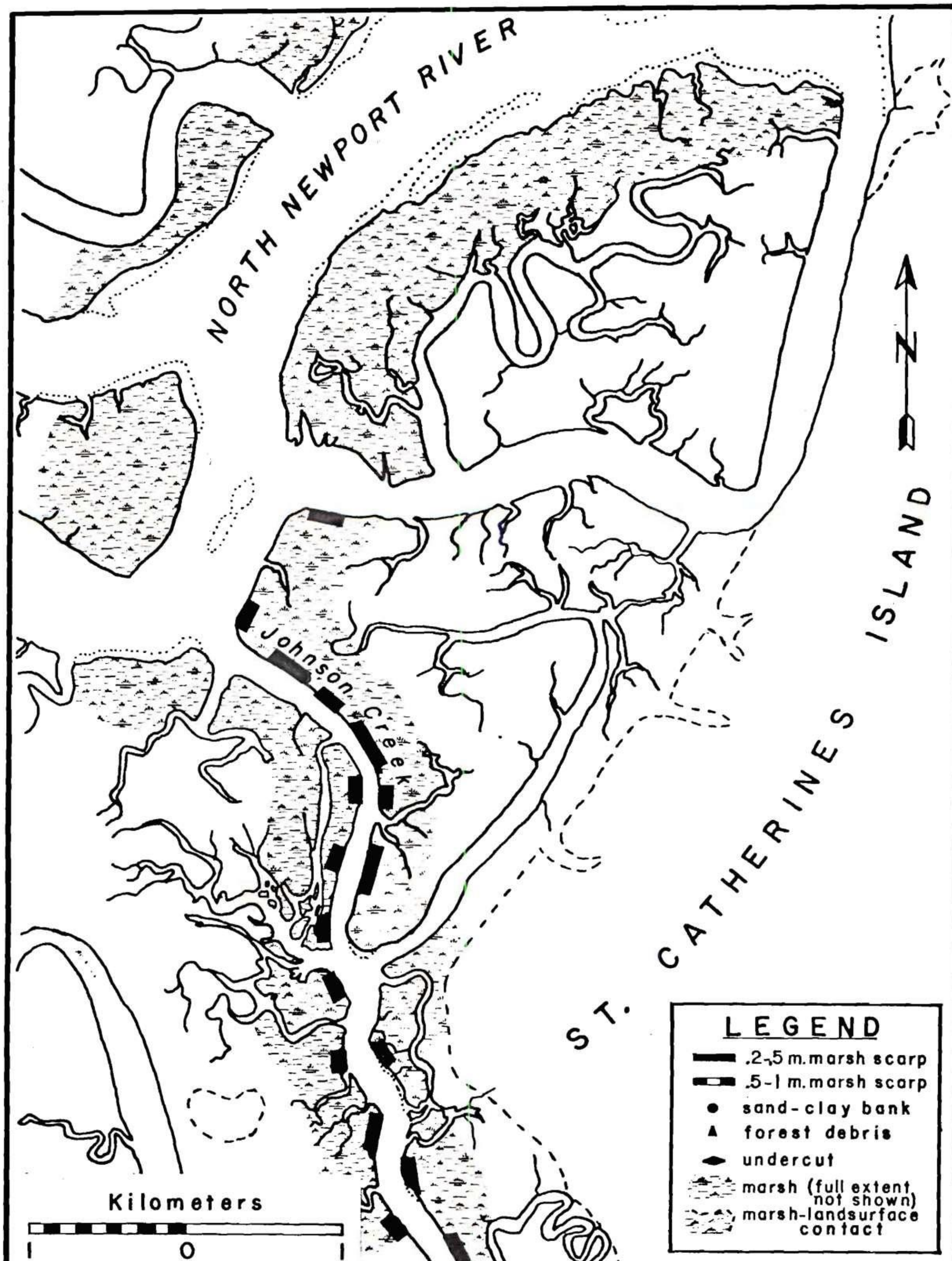

Figure 16. Erosion Site Locations; North Newport River to Johnson Creek

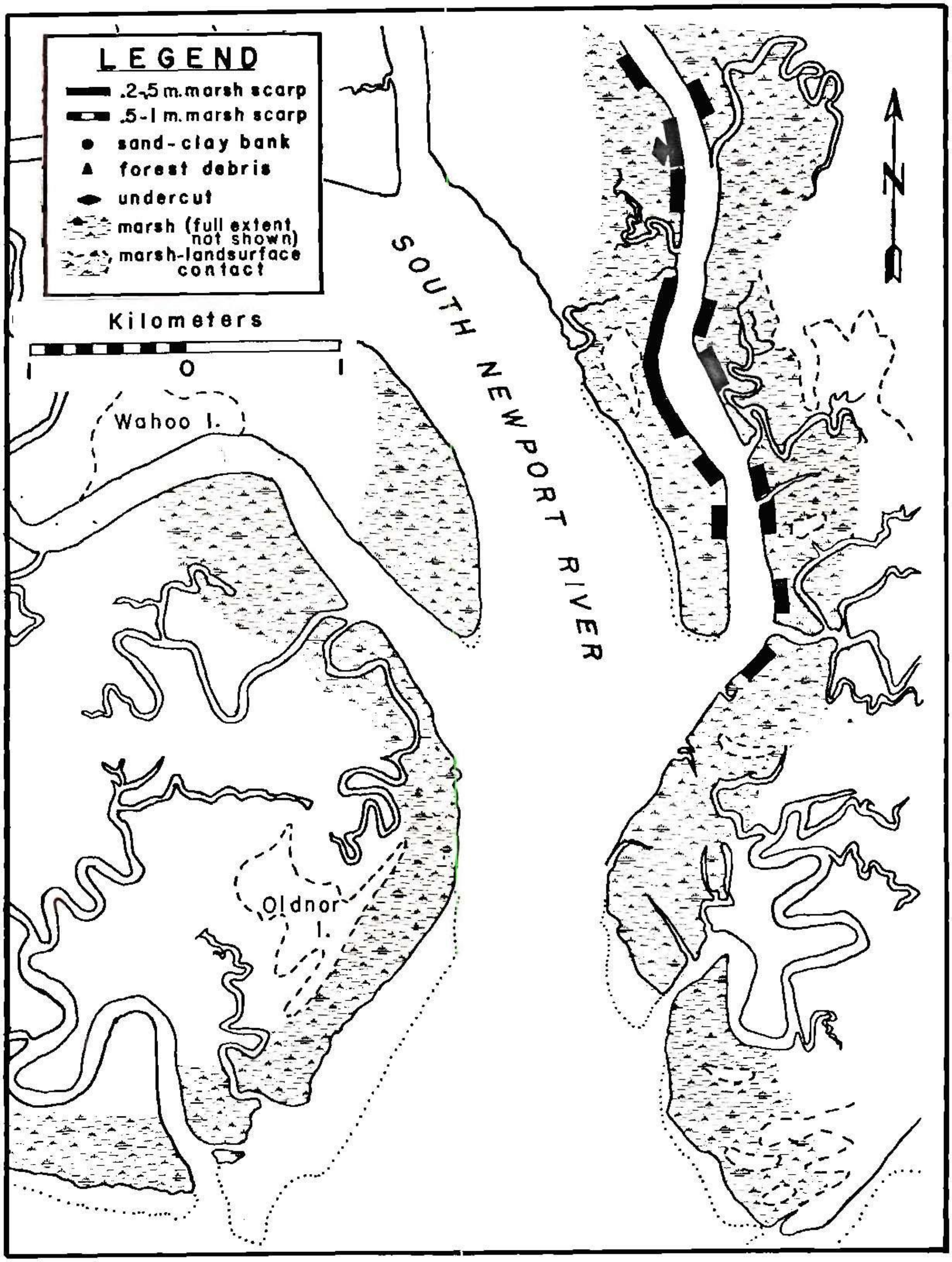

Figure 17. Erosion Site Locations; Johnson Creek to the South Newport River

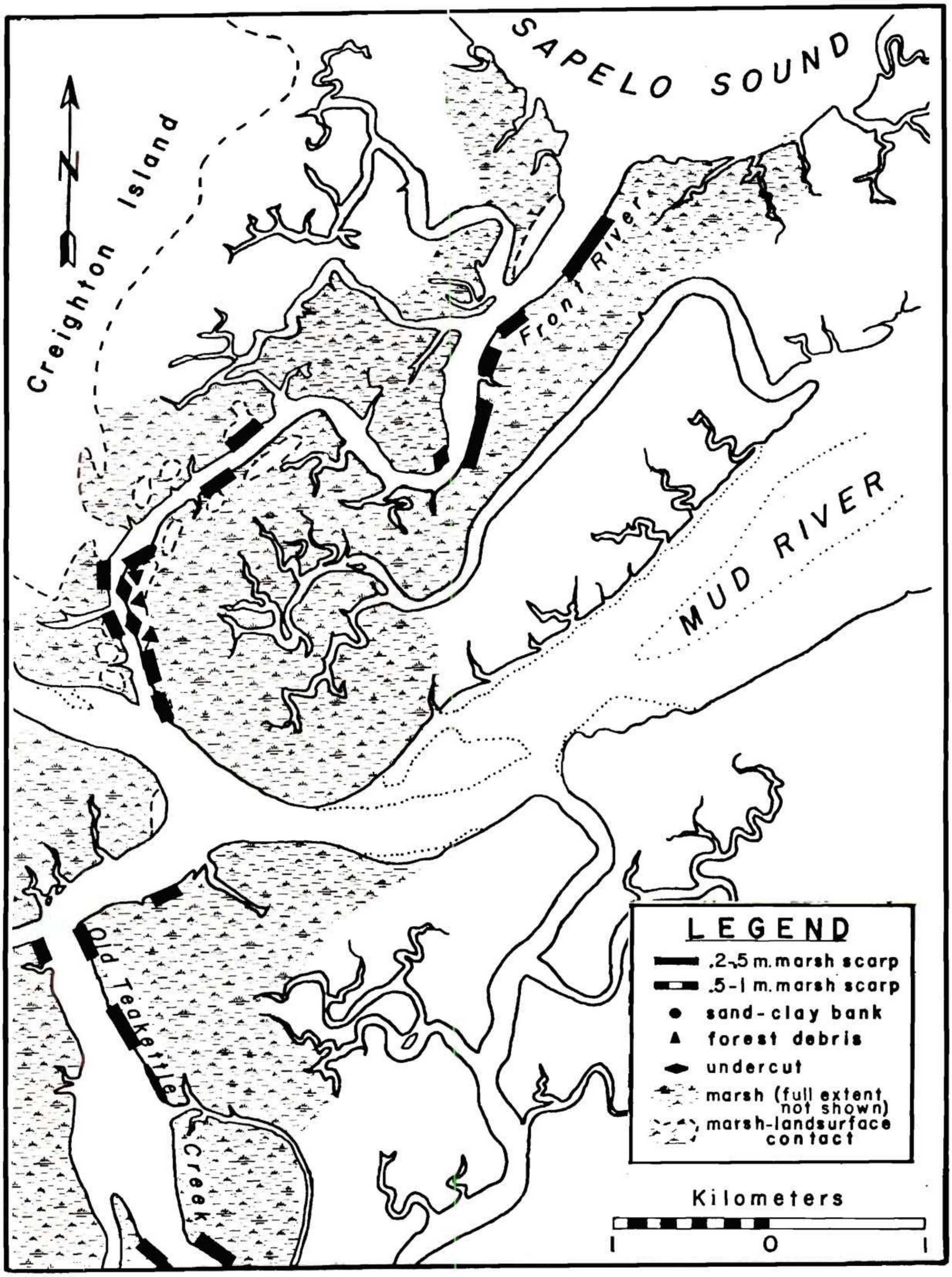

Figure 18. Erosion Site Locations; Sapelo Sound to Old Teakettle Creek

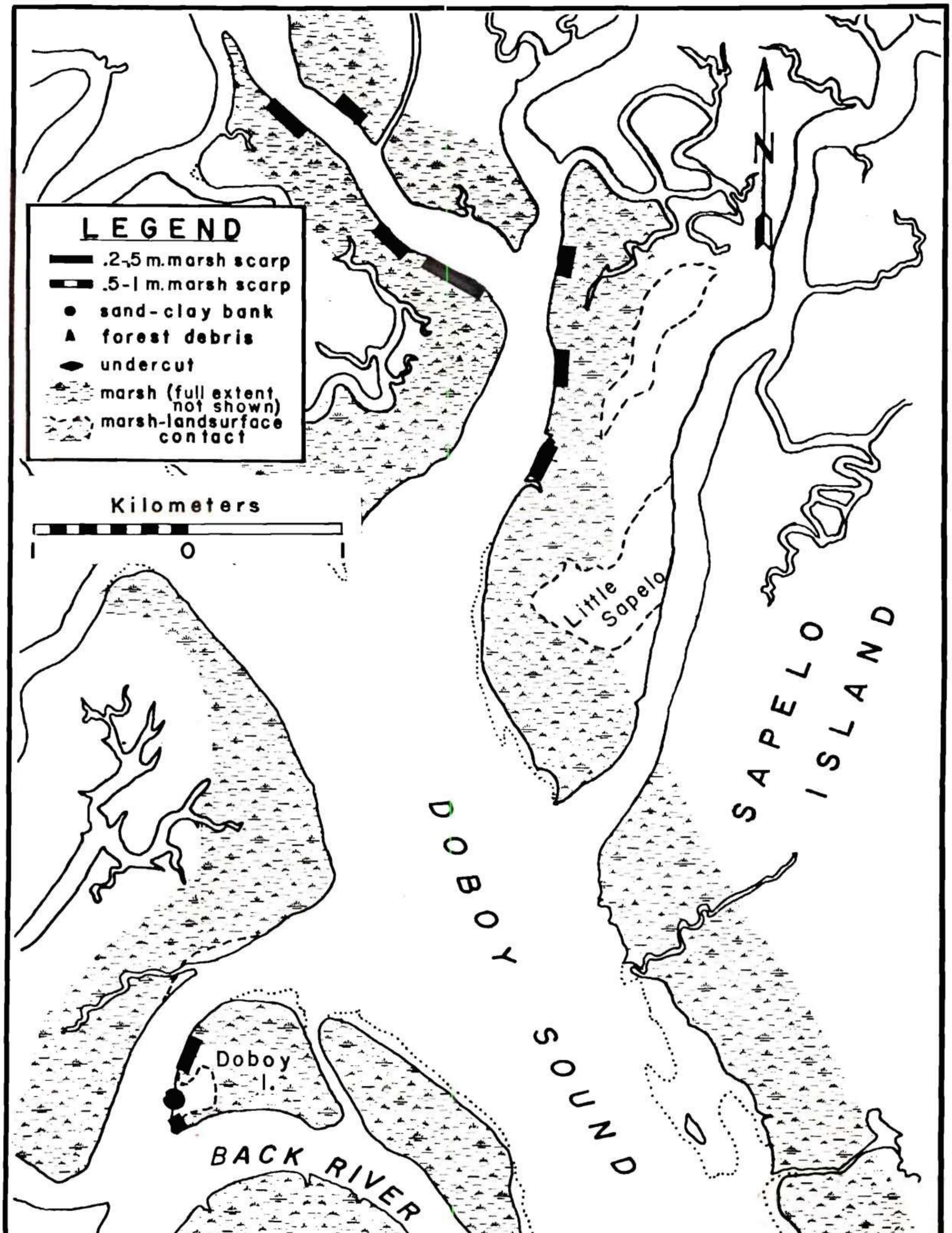

Figure 19. Erosion Site Locations; Old Teakettle Creek to Doboy Sound

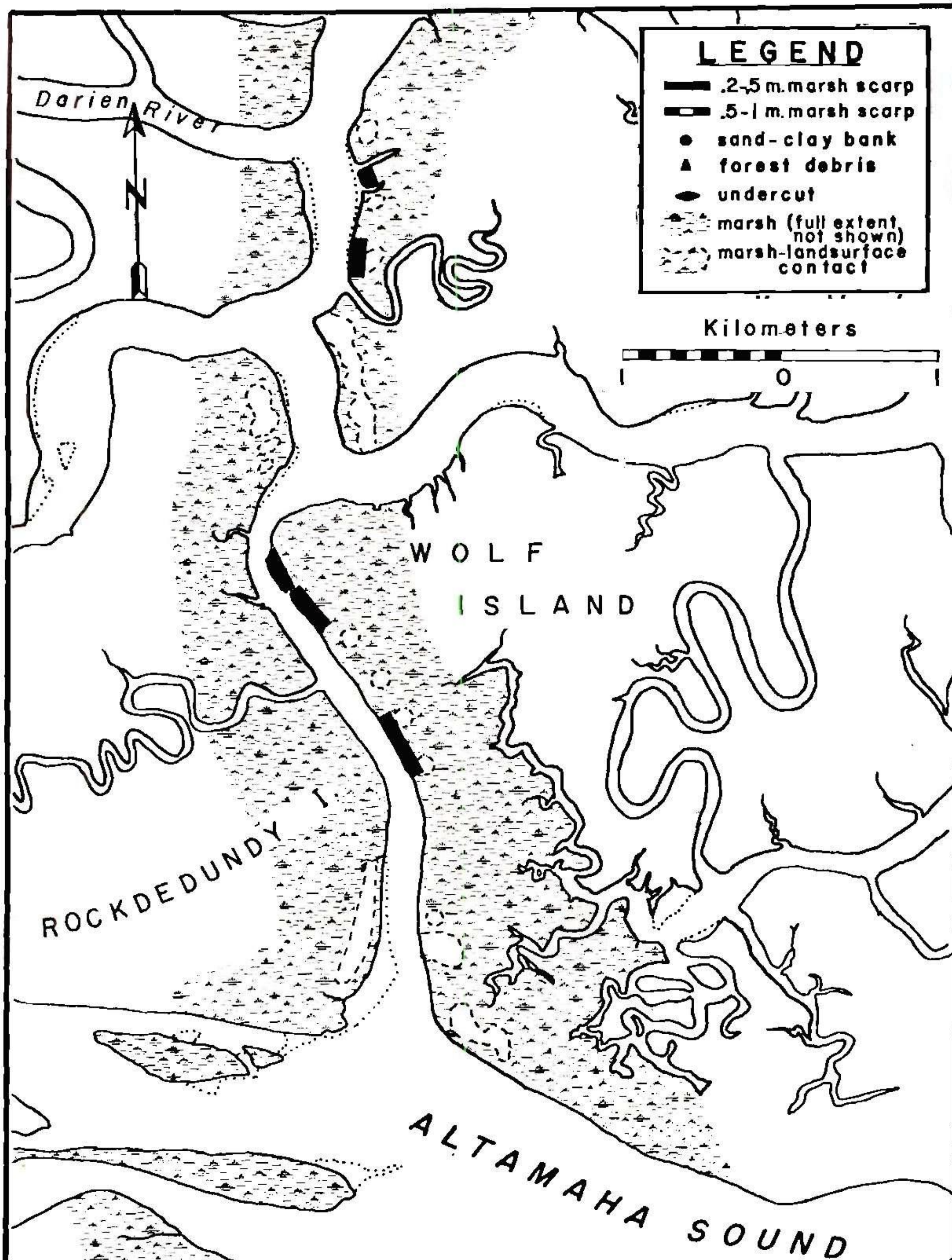

Figure 20. Erosion Site Locations; Darien River to Altamaha Sound

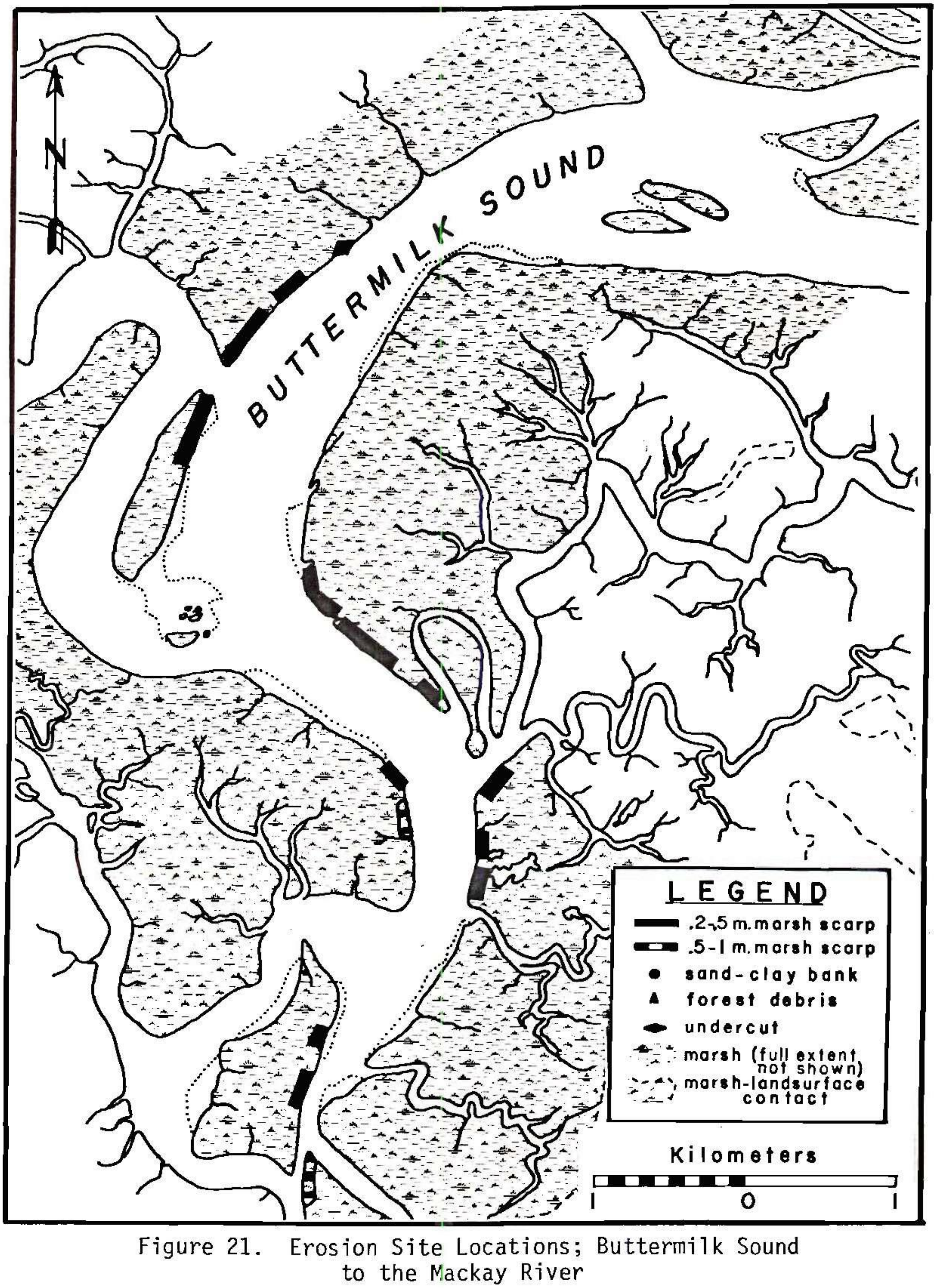

Figure 21. Erosion Site Locations; Buttermilk Sound to the Mackay River

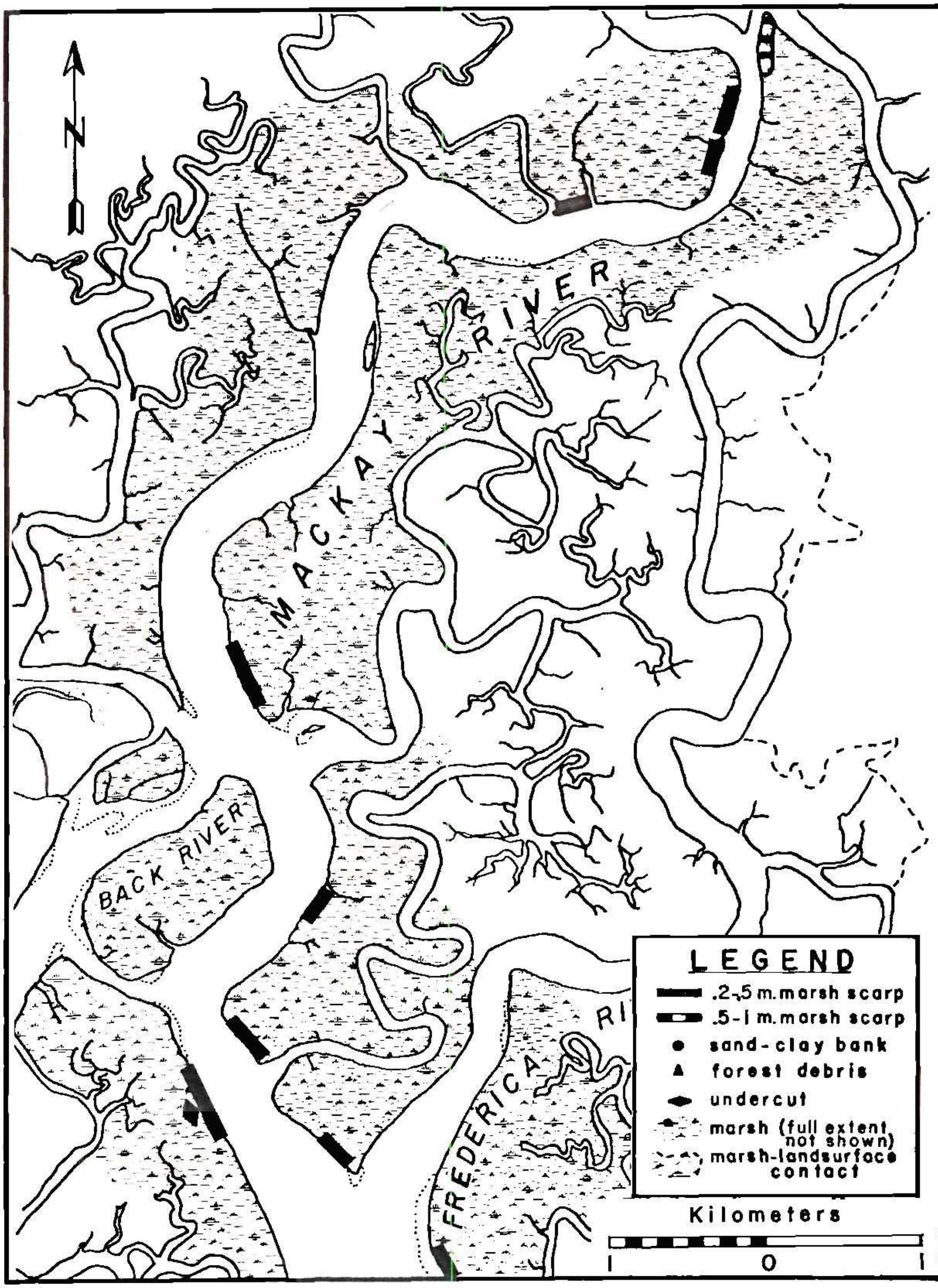

Figure 22. Erosion Site Locations; Mackay River to the Frederica River

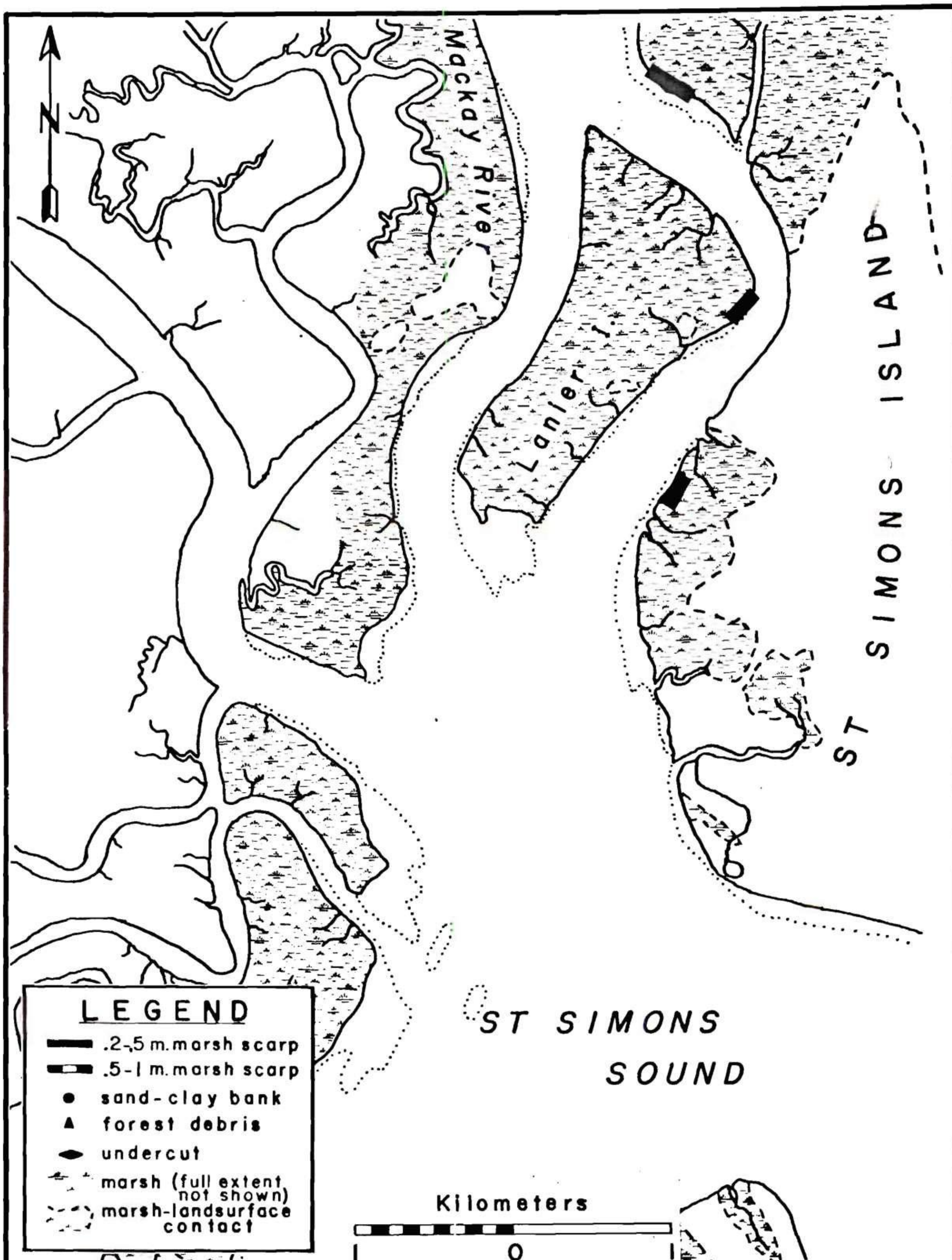

Figure 23. Erosion Site Locations; Frederica River to St. Simon's Sound

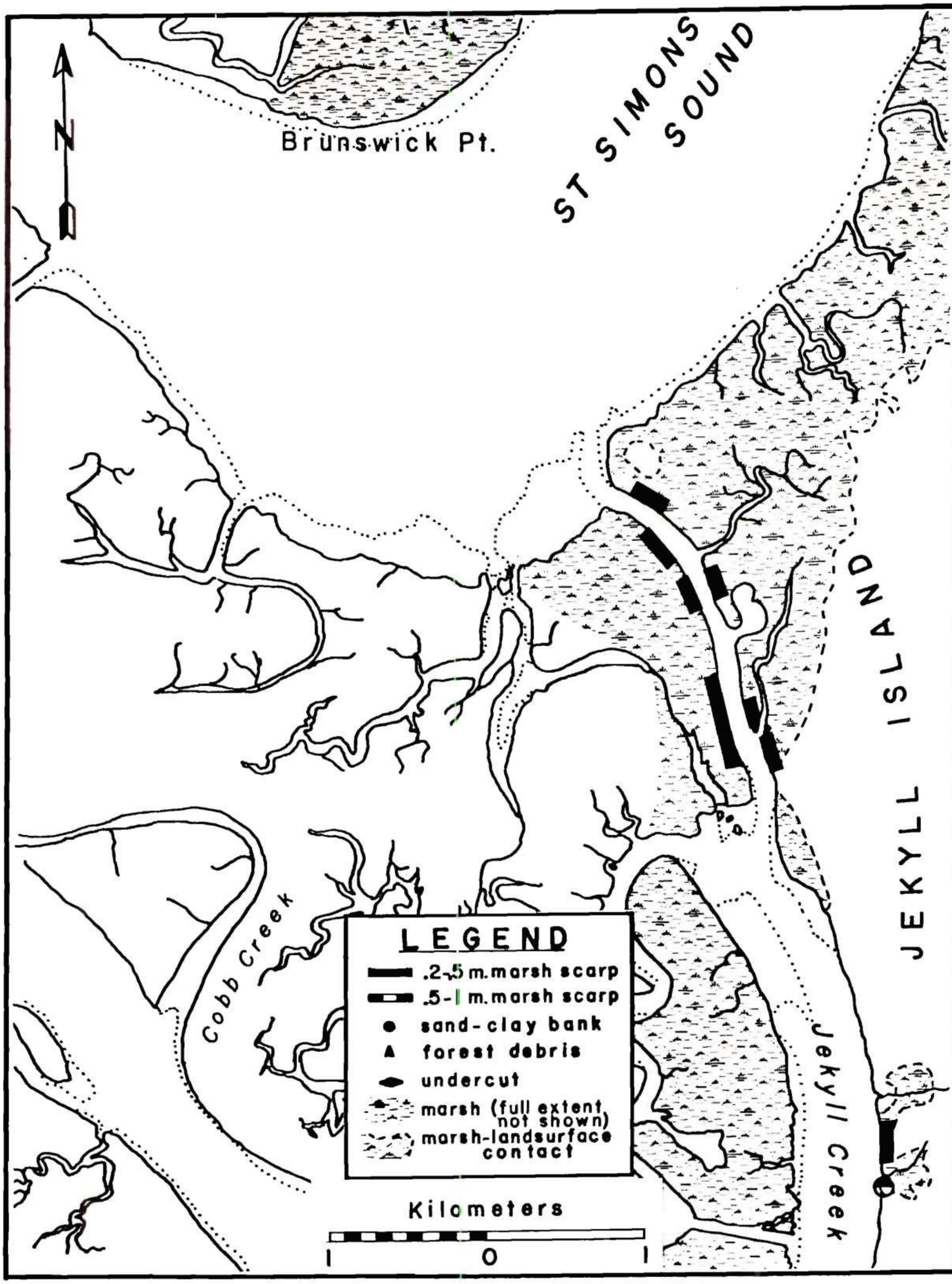

Figure 24. Erosion Site Locations; St. Simon's Sound to Jekyll Creek

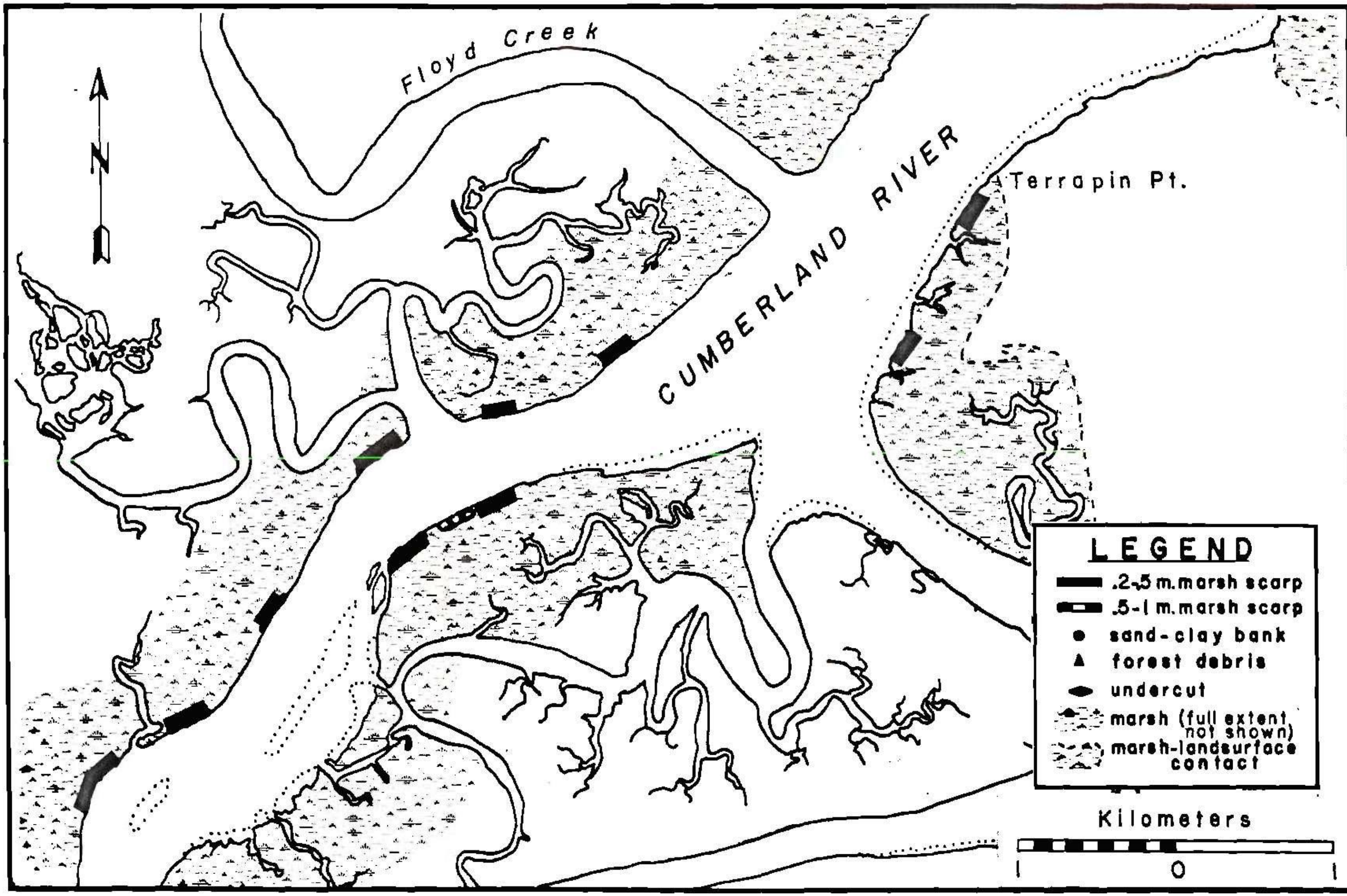

Figure 25. Erosion Site Locations; Terrapin Point to Cabin Bluff (Cumberland River)

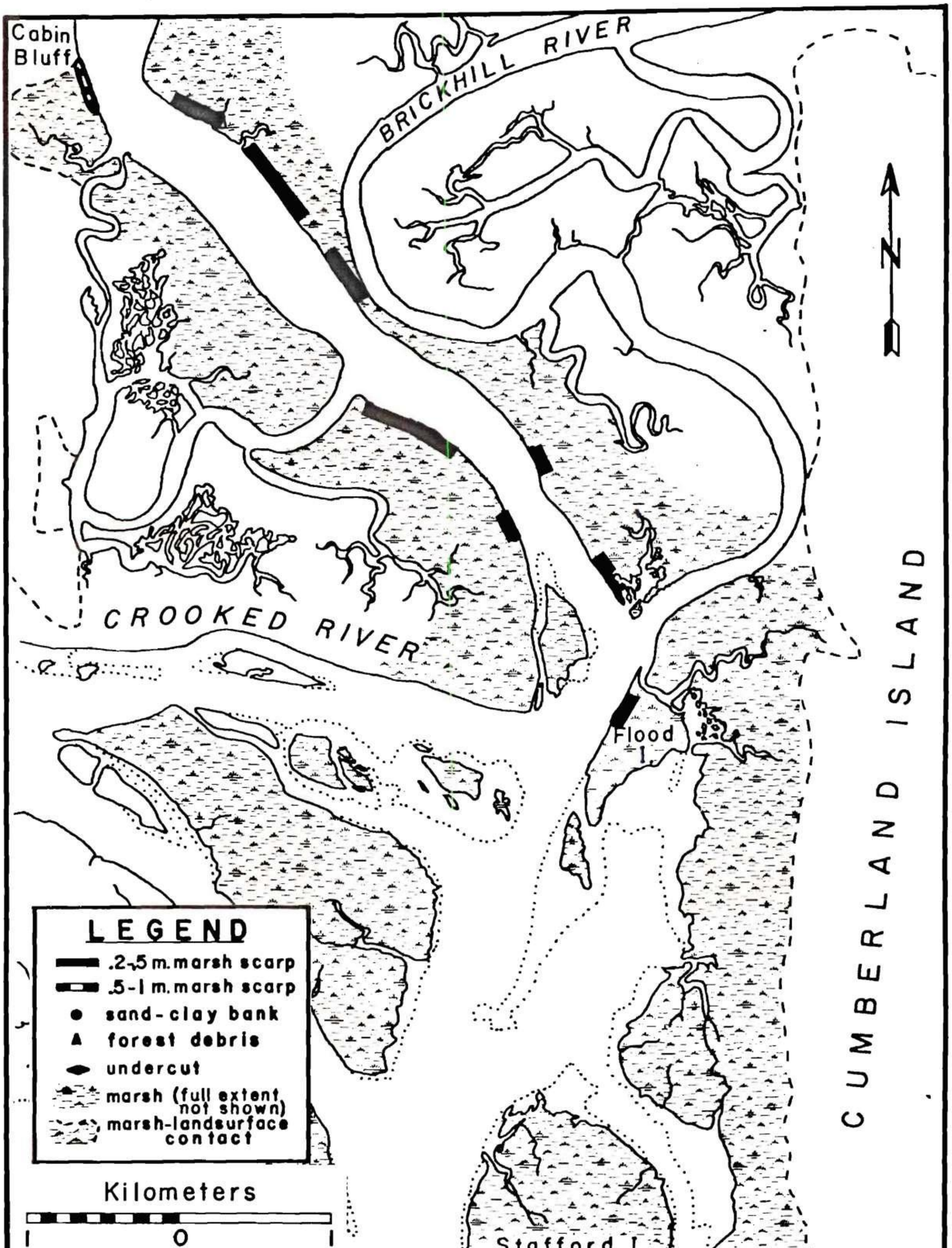

Figure 26. Erosion Site Locations; Cabin Bluff to Stafford Island

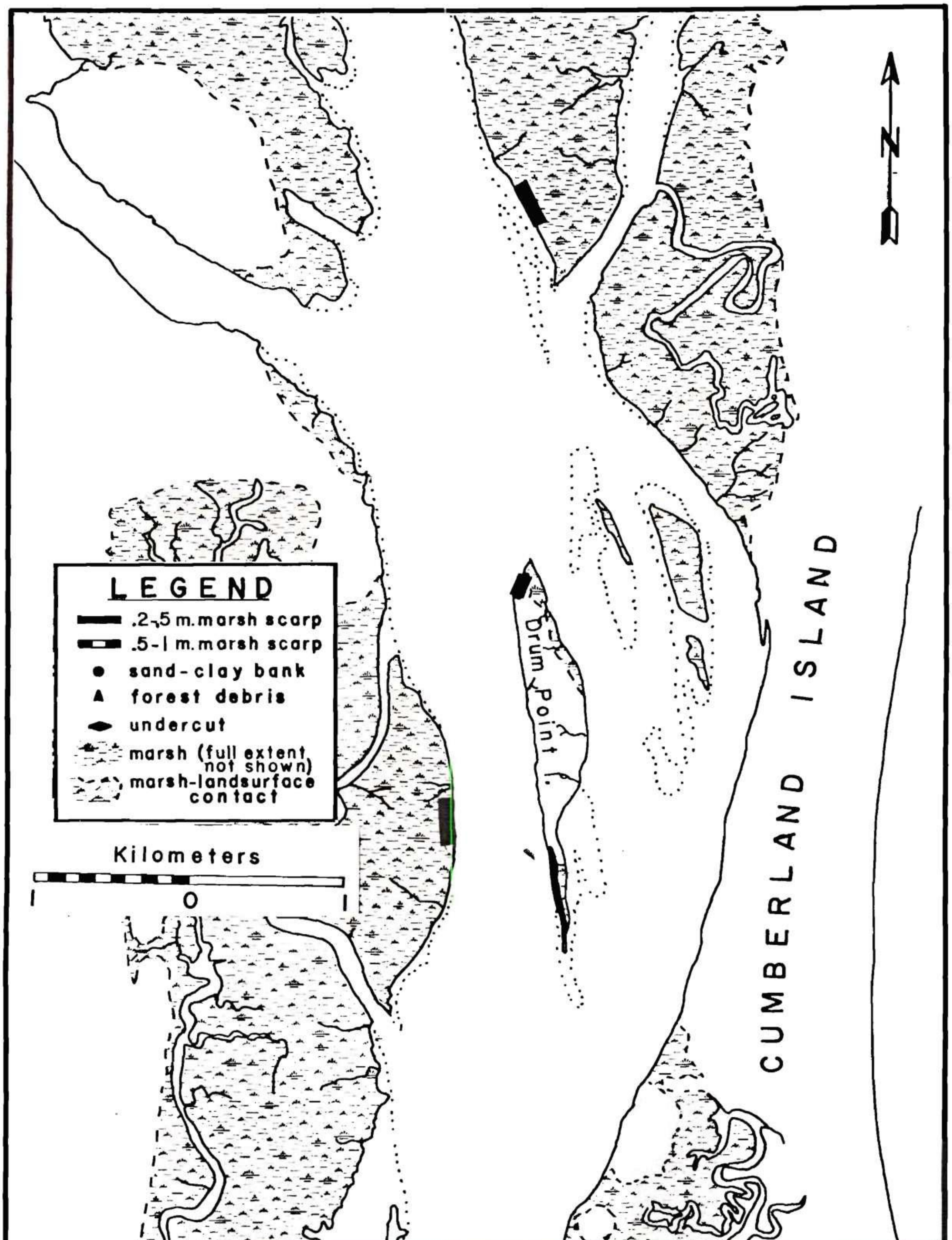

Figure 27. Erosion Site Locations; Stafford Island to Drum Point Island

erosion site maps presented herein. Approximately 52 percent of the two locations coincide. It was evident that dredging, particularly of narrow channels, was closely related to slumping of the channel sides (banks) and steepening of fore-marsh slopes. Waves approaching the steeply sloping shoreline expend a large portion of kinetic energy when they strike the shore without significant dissipation from bottom friction.

The qualitative results of this survey have resulted in a classification and description of eroding estuarine shoreline types. Two primary types of shorelines are recognized in the A.I.W.W. region (Table 2). Bellis _et al_. (1975) established a similar classification of the estuarine shoreline for the Albemarle-Pamlico region of North Carolina (Table 3). However, swamp forests (Type II), _Juncus roemerianus_ (Type II I B) and bluffs greater than 20 feet (Type I C) were nonexistent in the Georgia study area. Because of the similarity in response to erosional processes, low and high banks were considered as a single entity. Both the marsh and bank shorelines in Georgia were constantly subjected to morphological changes. The status of each was readily classified by their respective conspicuous physical features.

Marsh

A stable marsh consisted of a gentle fore-marsh slope generally fringed by a narrow region of secondary marsh growth. The energy of oncoming waves was dissipated on the fore-marsh slopes. The wave energy transmitted beyond the fore-marsh slope was not capable of producing more than a .2 meter scarp. Stable marshes were generally abundant

Table 2. Classification and Shoreline Types of the Intracoastal Waterway of Georgia

Type	Class	Dominant Features
Grass Marsh	Stable	Primary marsh terrace; extensive. Secondary marsh; narrow fringe. Scarp; .5m or less. Fore-marsh slope; gentle.
	Accretion	Primary marsh terrace; level with fore-marsh slope. Secondary marsh; prograding. Scarp; absent. Fore-marsh slope; gentle.
	Erosion	Primary marsh terrace; extent varies. Secondary marsh; detached marsh block. Scarp; .5m or greater. Fore-marsh slope; steep.
Sand and Clay Bank	Vertical Erosion	Land surface vegetation; low shrubs. Bank face; vertical. Slump-built toe.
	Undercut Erosion	Land surface vegetation; large trees. Bank face; undercut. Fallen trees litter bank base.

Table 3. Estuarine Shoreline Classification for the Albemarle-Pamlico Region of North Carolina (Bellis *et al*., 1975)

I. SAND and CLAY BANK	II. SWAMP FOREST	III. GRASS MARSH
A. Low (1-5 feet)	A. Cypress fringe (*Taxodium distichum*)	A. Smooth cordgrass (*Spartina alterniflora*)
B. High (5-20 feet)	B. Cypress-gum river swamp (*Taxodium distichum, Nyssa aquatica*)	B. Black needle rush (*Juncus roemerianus*)
C. Bluff (greater than 20 feet)		

where the estuary was wide and the channel was centrally located.

Accreting marshes prevailed in areas of excessive deposition, usually the inside of bends and sections of broad expanse. The fore-marsh slope and primary marsh terrace were nearly level and a wide zone of secondary marsh fringed the slope.

Eroding marshes had short and steep fore-marsh slopes. Scarp heights were generally between .5 to 1 meter, and were often fronted by detached marsh blocks. Eroding marsh was subjected to intense erosion during the period of mid to mean high water. During mid-tide the water surface was below the dense upper root mat of the marsh surface. Lacking the protective fore-marsh slope, wave energy was directed on the marsh scarp. Waves attacked and eroded the soft substrate material leaving the root mat undercut and unsupported. As the flooding tide raised the water level, the substrate continued to be removed by tidal scour. The sagging root mat eventually fell off producing V-shaped notches (Bellis et al., 1975) in the marsh scarp.

Wave crests entering newly formed notches converge, focussing their energy at the head of the notch. Rapid erosion at this point caused large sections to become breached and form detached blocks fronting the primary marsh terrace. The major root mat generally remained intact on blocks that were formed by undercutting or breaching. Many of these blocks were removed by tidal action or destroyed by continuing erosion. However, some of these vegetated blocks succeeded in re-establishing themselves to form a secondary marsh. These blocks acted as natural barriers that protected the primary marsh terrace from further erosion. The re-establishment of marsh blocks was previously observed by Richards (1934).

Bank

Bank type shorelines were created wherever the estuary intersected the upland sand surfaces. There were two distinct forms of eroding banks along the A.I.W.W. (Table 2). Both were eroded by wave attack only during high water, spring tides and storm surges. Bluff retreat was sporadic and related to bluff failure. Thus the bluff line was constant during the undercutting process but retreated in "jumps" during bluff failure stages. The two forms were categorized by erosion features on their faces that were related to the upland surface vegetation. Land surfaces vegetated with large trees produced severely undercut banks. The massive tree roots supported the upper portion of the bank until their own weights, or a strong wind, toppled them over the edge. The base of undercut banks were abundantly lined with fallen, decaying trees.

Where the bank surface was vegetated with small shrubs and bushes, the supporting root structure of larger trees was absent. As wave erosion removed material from the base of the bank, the face slumped from lack of support. This produced a nearly vertical face on the bank and a prominant toe remained between periods of wave erosion.

Erosion Control Structures

Erosion control structures currently employed on the A.I.W.W. consisted of bulkheads and revetments (Table 4). The use of various structures was site-dependent and related to the predominate type of

Table 4. Shoreline Protection Structures Found on the Intracoastal Waterway of Georgia

Revetments

- Rubble
- Broken concrete slab
- Stone
  - ∿ 50 lb
  - ∿ 1 lb
- Sandbag

Bulkheads

- Concrete
  - Pre-cast
  - Asbestos
  - Poured wall
  - Block
- Wood
  - Treated tongue and groove
  - Vertical log
  - Stacked railroad ties
- Aluminium
- Corrugated steel
- Brick

erosion, foundation conditions, status of adjacent land forms, and cost. Unfortunately, economics rather than effectiveness was generally the deciding factor for project development. Too often private citizens either cannot afford the proper structure or rationalize the use of less costly and inferior materials.

Bulkheads

Defined as "retaining walls holding back the ground from sliding into a channel or to protect a shore from wave erosion," bulkheads were the most widely used system of erosion control on the A.I.W.W.

Treated wooden planks with tie-back anchors were the most common commercial bulkhead encountered (Fig. 28). Usually 2 1/2 lbs. pressure-treated planks are recommended for use against marine boring organisms. Costs generally run $50-100/linear foot. This type of bulkhead was particularly well suited for protection of low banks (1 - 2 meter) in the estuarine environment.

At one site, 8-inch diameter logs had been placed vertically and spaced about one meter apart. In an attempt to protect a narrow marsh fringe, this "open-bulkhead" accomplished little except to provide perching sites for birds.

Railroad ties, usually stacked three or four high, were employed at several locations. Although they provide adequate protection, their life spans are short (1 - 5 yrs.) due to failures in design.

A variety of concrete bulkhead structures exist. The flexability and versatility of concrete has made it very popular to "do-it-your-selfers." With proper guidance in engineering and construction methods,

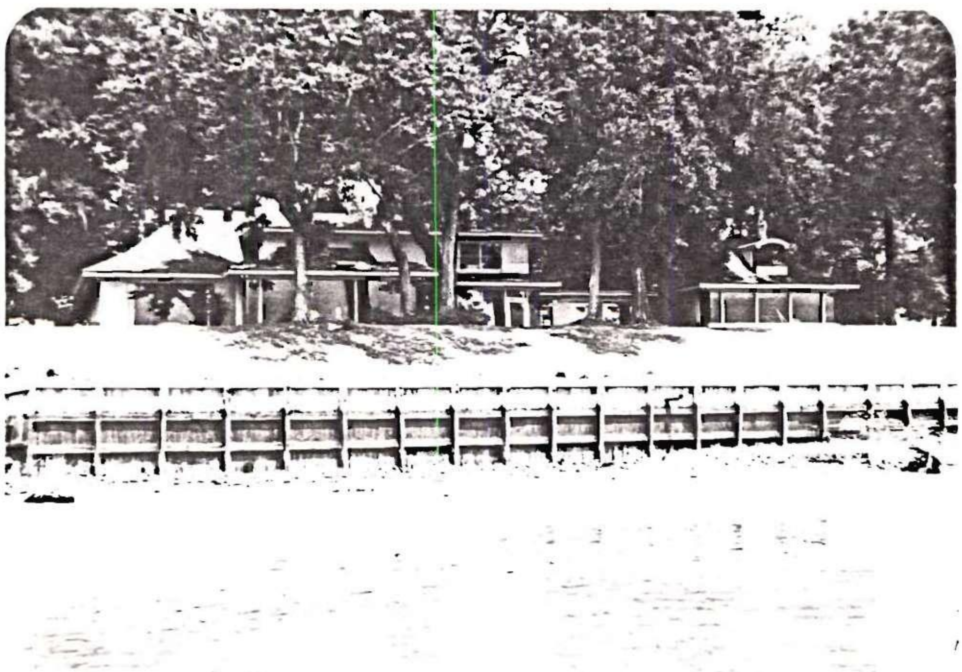

Figure 28. Treated Wood Bulkhead Commonly Used on the A.I.W.W.

structures such as concrete block or poured walls can provide a long-term, efficient structure. Commercial pre-cast concrete-asbestos bulkheading is more expensive ($200 - $300/linear foot) than treated wood and has limited use in this environment.

Use of aluminum bulkheads in the estuarine environment has been introduced in recent years and they are gaining in popularity. Comparable ($80 - $100/linear foot) to treated wood, they are light-weight and can be installed quickly.

Steel bulkheads are costly ($1,000 - $1,200/linear foot), over-designed structures for small estuaries. Their use should be limited to larger estuaries.

Brick walls are often used to retain back-filled material where property has been extended or leveled. This type of wall is generally non-effective in preventing river-source erosion. Usually constructed directly on the land surface, the base is subjected to undercutting by which eminent wall failure occurs.

Revetments

Revetments take on innumerous forms. Material (rip-rap) used in most revetments was obtained free of charge and consists of everything from demolished buildings to junked cars (Fig. 29A). Rip-rap material was often dumped haphazardly on the bank face without a preconceived plan. This seldom provided adequate protection as bank soil scours from beneath the rip-rap. It is also unsightly and dangerous to both boaters and curious persons. However, when properly engineered, revetments were one of the more effective structures of estuarine control.

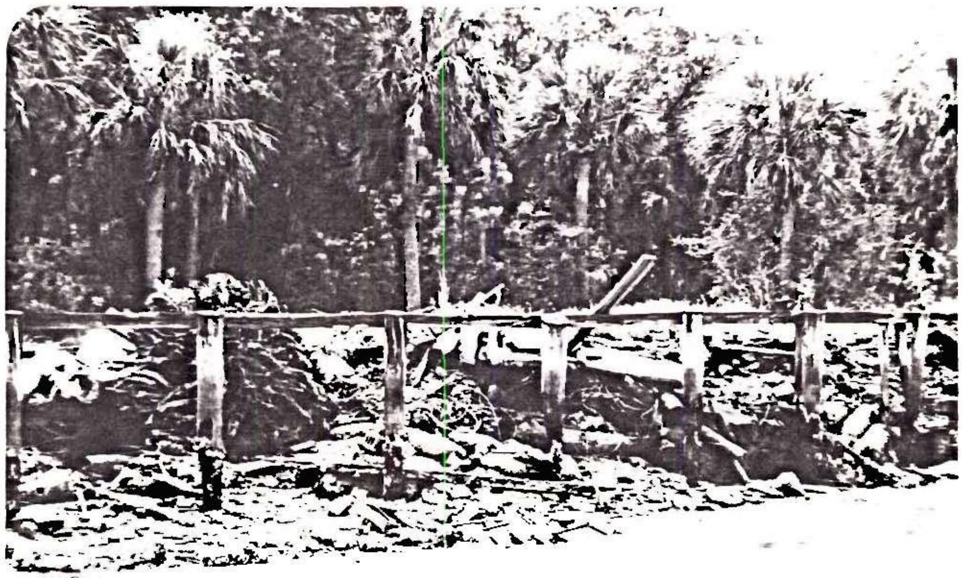

Figure 29. A) Debris Used as Revetment Rip-Rap
B) U.S. Army Corps of Engineers' Revetment

The Corps of Engineers have implaced several engineered revetments to protect shores of artificial cuts (Fig. 29B). Stones weighing over 50 lbs. were placed over filter cloth and treated wood mat. However, transportation costs combined with installation difficulties make these structures extremely expensive (\$15 - \$20/sq. yd.).

Sand bag revetments can be installed easily, are relatively inexpensive (\$2 - \$5 per 5x7 bag) but provide only a relatively short-term protection. They are suitable as an interim control device or temporary repair.

Geotechnical Evaluation

Car tires were used to construct an inclined revetment/mat, an inclined revetment and a vertical revetment. Sections were completed in May, July and August (1977), respectively. Monitoring of the revetments and marsh consisted of monthly photographs, visual inspection of the system and geotechnical tests.

Spartina alterniflora readily inhabited the tire mat, and to a lesser degree, the lower tires of the inclined revetment. Originally, plans were made to sprig *Spartina* within the mat. However, in less than two months subsequent to completion (before the sprigging was accomplished), *Spartina* began sprouting. By late summer (1977) the grass flourished. Measurements made in August, on a randomly selected tire, revealed 19 culms of *Spartina alterniflora* ranging in height from 20 cm to 1.4 meters. Plants in the marsh fronting the mat averaged only 50 cm in height.

The revetments remained in excellent condition despite several severe storm surges. They required no maintenance throughout the first year. The polypropylene rope used to fasten the inclined revetment/mat did show signs of bleaching, a characteristic of ultra-violet light degeneration. However, the hand-tied knots were tight and the tires remained secure.

Elevations of the tires were measured at each transect in September (1977) and again in March (1978). The Shor-J profiling method, as described by Oertel, Chamberlain and Larsen (in prep.), was used. Profiles B, C, and D reveal a slight settling of the tires, approximately 2 - 3 cm in each case (Fig. 30). This minor settling was probably due to readjustment following construction, but demonstrated the flexibility of modules to shift with no apparent weakening in their design.

Grain-Size Analysis

Previous to installing the revetments, the adjoining Pleistocene bank was the primary source of coarse sediment within this study area. Results of grain-size analysis, sand-silt-clay percentages, mean values and standard deviation are presented in Table 5. Statistical parameters, listed in Table 6, were calculated by the graphic method of Folk and Ward (1957) and obtained through the modified computer program of Slatt and Press (1976). General results indicate the marsh sediment analyzed is moderately to well sorted fine sand. The percentage of mud-size sediment was low, ranging from .36 percent at station C2 to 5.34 percent at station E2. Similar results were obtained by Scott (1976) in his examination of Pleistocene sand formations in Georgia. Investigations of marsh sediments by other workers (Cammen *et al*., 1974; Terry *et al*.,

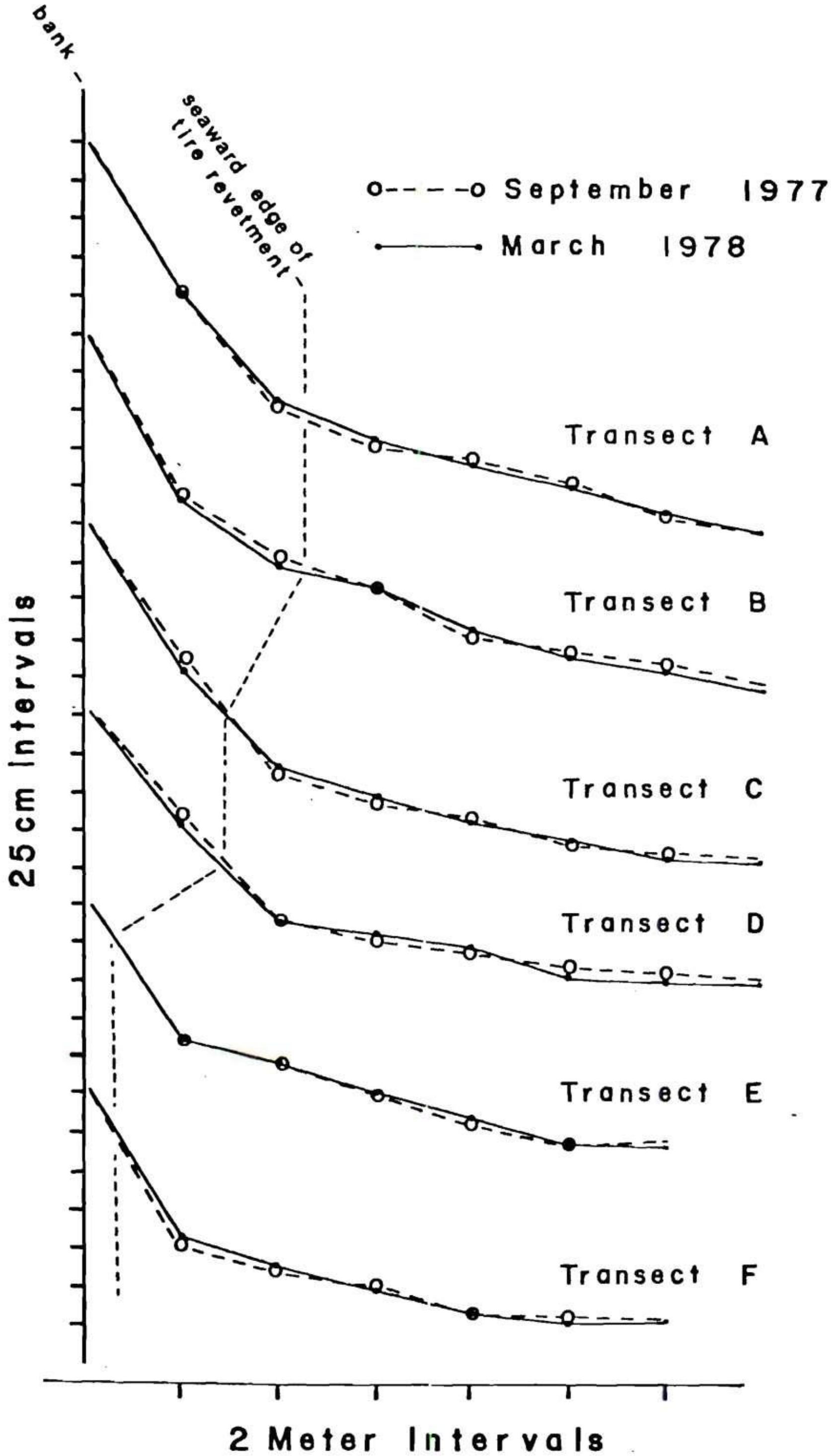

Figure 30. Elevation Profiles of the Tire Revetments and Marsh Surface

Table 5. Grain Size Distributions

Transect	Station	Sand (%) 7/77	9/77	11/77	1/78	3/78	Mean	Std. Dev.	Silt (%) 7/77	9/77	11/77	1/78	3/78	Mean	Std. Dev.	Clay (%) 7/77	9/77	11/77	1/78	3/78	Mean	Std. Dev.
A	1	93.3							4.8							1.9						
	2	98.1	98.6	99.3	89.8	99.0	96.96	4.028	1.3	.7	.3	9.5	.6	2.48	3.941	.6	.6	.4	.7	.4	.54	.134
	3	99.4	99.5	99.2	99.5	99.2	99.36	.152	.2	.1	.3	.2	.5	.26	.152	.4	.5	.4	.3	.3	.38	.084
	4	98.3							.7							1.0						
B	1	94.9							2.8							2.4						
	2	98.9	99.1	97.7	98.6	99.0	98.66	.568	.6	.3	1.8	.5	.6	.76	.594	.6	.7	.5	.9	.4	.62	.192
	3	99.6	99.3	99.5	99.7	99.6	99.54	.152	.2	.2	.1	.2	.4	.22	.110	.3	.6	.4	.2	.1	.32	.192
	4	—							—							—						
C	1	90.4							6.6							3.0						
	2	99.7	99.7	99.5	99.5	99.8	99.64	.134	.1	.2	.2	.2	.2	.18	.045	.2	.1	.3	.3	0.0	.18	.130
	3	99.6	99.4	99.6	99.6	99.7	99.58	.110	.1	.3	.3	.2	.2	.22	.084	.3	.2	.1	.2	.1	.18	.084
	4	98.3							.6							1.1						
D	1	89.8							7.4							2.8						
	2	—	98.5	98.8	98.9	98.5	98.68	.207	—	.7	.5	.4	1.1	.68	.310	—	.8	.7	.7	.5	.67	.126
	3	89.0	99.1	99.0	99.3	99.3	97.14	4.552	7.3	.2	.2	.3	.4	1.68	3.143	3.7	.7	.9	.5	.3	1.22	1.404
	4	97.9							1.0							1.1						
E	1	90.1							8.4							1.5						
	2	99.4	91.5	94.4	91.3	96.8	94.68	3.478	.2	6.8	4.0	6.9	2.9	4.16	2.818	.4	1.7	1.6	1.9	.3	1.18	.766
	3	98.0	92.8	99.5	99.4	99.4	97.82	2.874	.9	6.0	.3	.3	.2	1.54	2.509	1.2	1.2	.2	.4	.4	.68	.482
	4	94.0							3.6							2.4						
F	1	—							—							—						
	2	99.2	98.7	98.9	97.4	97.4	98.32	.859	.5	.6	.2	1.6	1.7	.92	.683	.3	.7	.9	1.0	.7	.72	.268
	3	92.8	99.0	99.1	98.4	98.6	97.58	2.687	3.7	.6	.1	.6	.9	1.22	1.420	3.6	.5	.8	.8	.4	1.22	1.342
	4	89.8							6.1							4.1						

Table 6. Grain Size Statistical Parameters

Transect	Station	Graphic Mean (M_z) 7/77	9/77	11/77	1/78	3/78	Mean	Std. Dev.	Inclusive Graphic Skewness (Sk_1) 7/77	9/77	11/77	1/78	3/78	Inclusive Graphic Standard Deviation (SD) 7/77	9/77	11/77	1/78	3/78
A	1	2.75							.45					.92				
	2	2.29	2.15	2.24	2.27	2.17	2.22	.065	.21	.08	.03	.45	.06	.59	.44	.45	1.04	.44
	3	2.27	2.32	2.22	2.23	2.24	2.25	.040	.03	.16	.04	.04	.04	.43	.52	.45	.45	.46
	4	2.43							.16					.57				
B	1	2.54							.11					.63				
	2	2.32	2.28	2.29	2.28	2.25	2.28	.025	.18	.18	.19	.19	.18	.57	.56	.56	.57	.56
	3	2.40	2.38	2.33	2.30	2.28	2.34	.051	.05	.13	.16	.16	.17	.40	.57	.56	.53	.55
	4	2.88							.51					1.15				
C	1	—							—					—				
	2	2.48	2.31	2.22	2.20	2.23	2.29	.115	-.27	.02	.02	.02	.02	.41	.44	.44	.43	.44
	3	2.48	2.41	2.31	2.31	2.08	2.32	.151	-.09	.05	.03	.01	.05	.39	.40	.43	.44	.41
	4	2.56							.19					.51				
D	1	2.87							.50					1.12				
	2	—	2.49	2.46	2.44	2.49	2.47	.025	—	.10	.13	.17	.09	—	.56	.55	.55	.58
	3	3.00	2.52	2.44	2.37	2.42	2.55	.257	.45	.07	.17	.11	.13	1.14	.55	.52	.55	.54
	4	2.58							.02					.54				
E	1	2.85							.46					1.02				
	2	2.48	2.84	2.81	2.82	2.52	2.69	.178	-.13	.45	.31	.46	.08	.40	1.00	.75	1.02	.55
	3	2.59	2.77	2.53	2.49	2.49	2.57	.117	-.01	.46	-.01	.04	.03	.50	.87	.48	.50	.51
	4	2.58							.22					.70				
F	1	—							—					—				
	2	2.60	2.58	2.56	2.77	2.82	2.67	.120	.06	.03	.02	.23	.27	.48	.53	.51	.69	.66
	3	2.91	2.57	2.85	2.86	2.97	2.83	.154	.48	.03	.27	.29	.35	1.07	.53	.62	.61	.59
	4	2.83							.44					1.31				

1974; and Teal and Kaniwasher, 1961) also produced similar particle size distributions. Pferd (1970) reported slightly lower sand contents (62.5 - 70.8%) for a similar salt-marsh environment at Sapelo Island, Georgia. The lower sand content can be attributed to a more mature marsh and a different sediment source.

Stations along transects A through D, which cross the inclined revetment/mat and inclined revetment, produced a generally higher percentage of sand-sized material (96.96 - 99.68%) than those stations along the vertical revetment transects E and F (94.68 - 98.32%). Samples analyzed from station 2 also contained a smaller average graphic mean than those sediments of station 3 (Table 6).

Tires of the inclined/mat and inclined revetment trapped and held sand-size sediment, both within their centers and in the immediately adjacent marsh. The finer sediment accumulated in the tire centers as sediment-laden water spilled into the cavity and was held until the water drained through the substrate, leaving the finer material behind.

Unit Weight

Individual dry-unit-weight values ranged from 1.02 gm/cc to 1.97 gm/cc (Appendix A). Values per station did not change substantially throughout the study (Figs. 31 through 36). Water content had an inverse relationship on unit-weight (Figs. 31 through 36).

Mean dry-unit-weight values ranged from 1.41 gm/cc to 1.62 gm/cc (Table 7). Revetment design apparently produced distinct variations in sediment unit-weight (Table 7). Mean values from stations 2 and 4 of the inclined revetment/mat were relatively equal, and lower, than

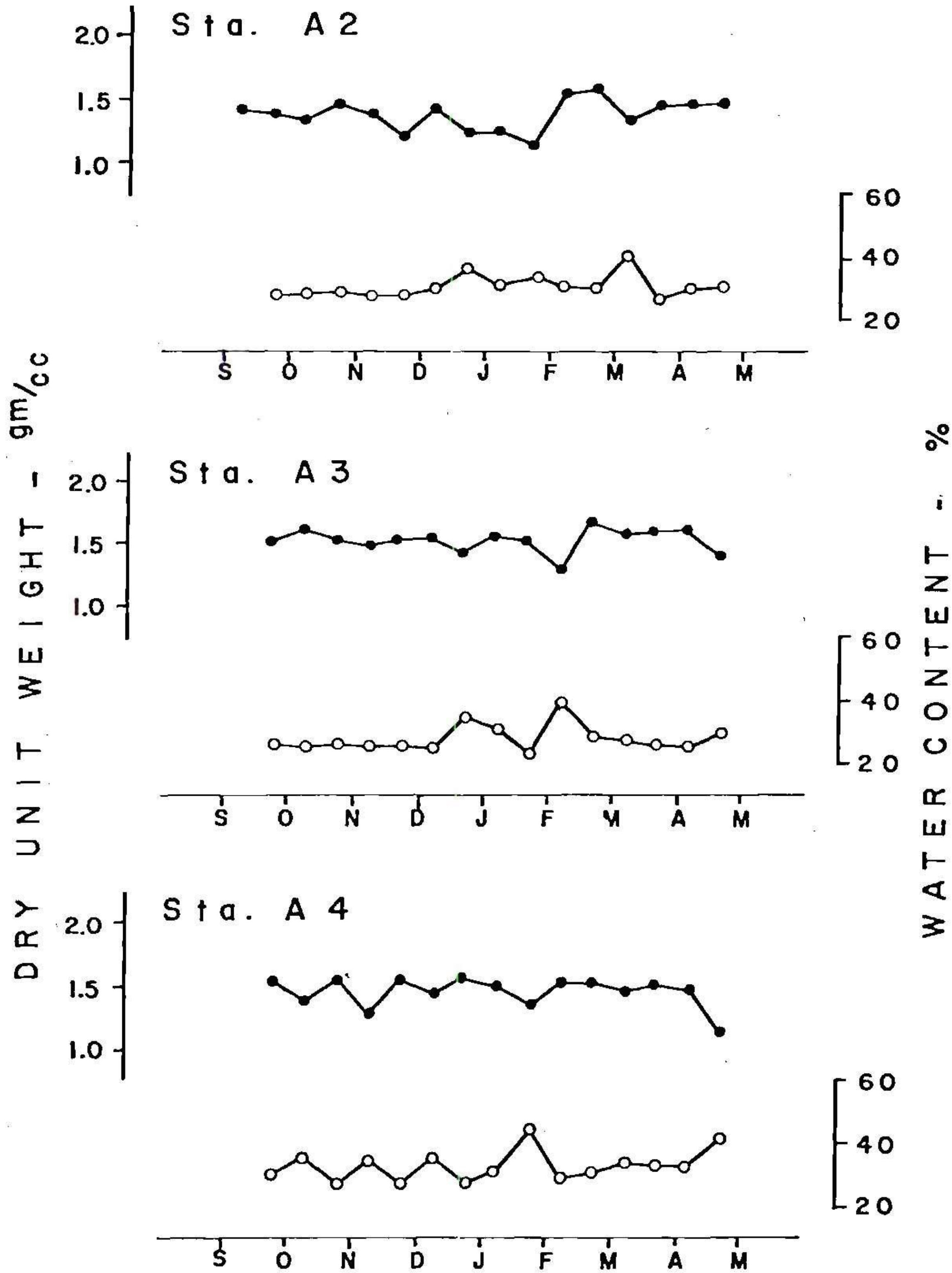

Figure 31. Relationship Between Unit Weight (•) and Water Content (o); Transect A

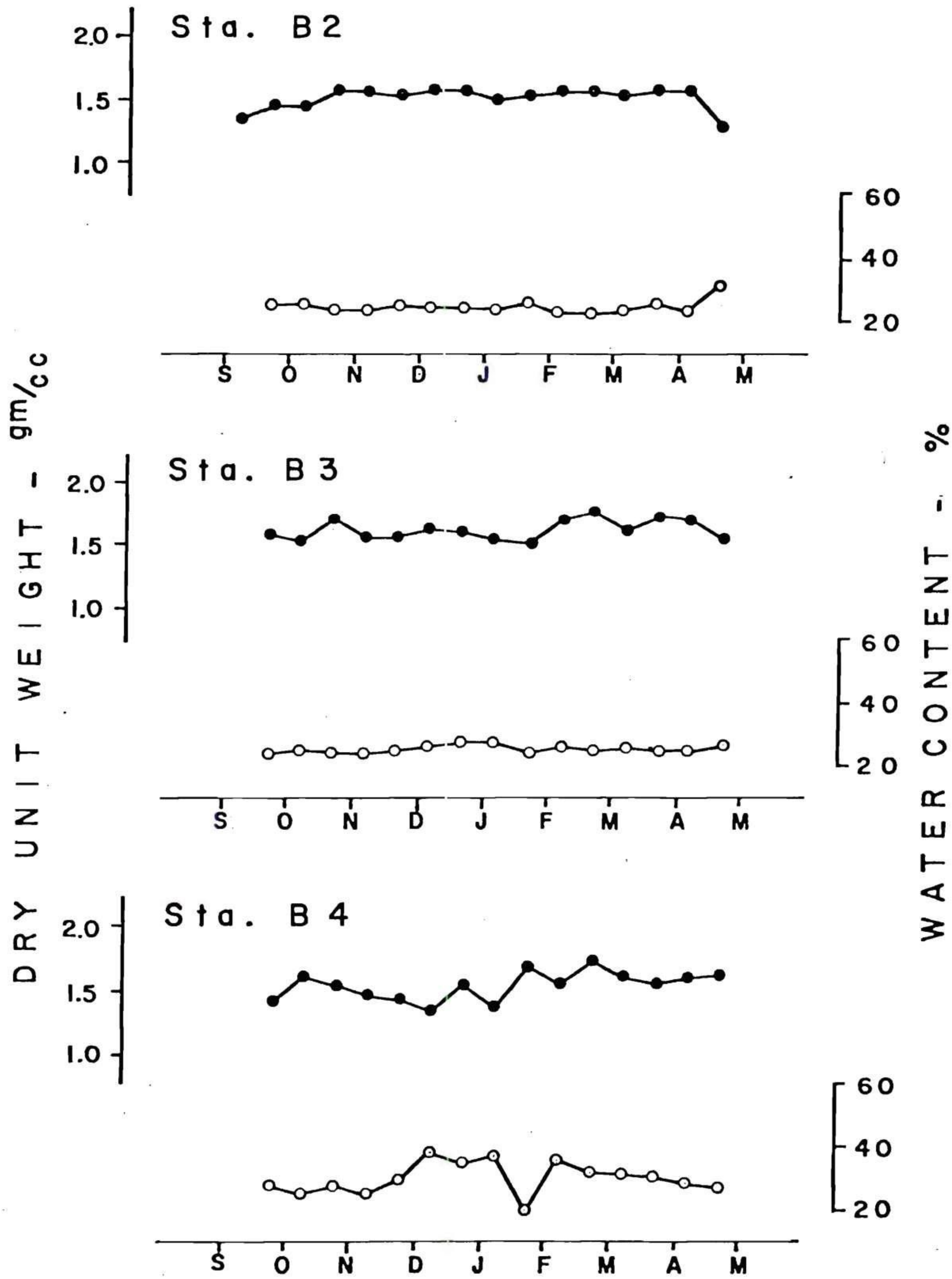

Figure 32. Relationship Between Unit Weight (•) and Water Content (o); Transect B

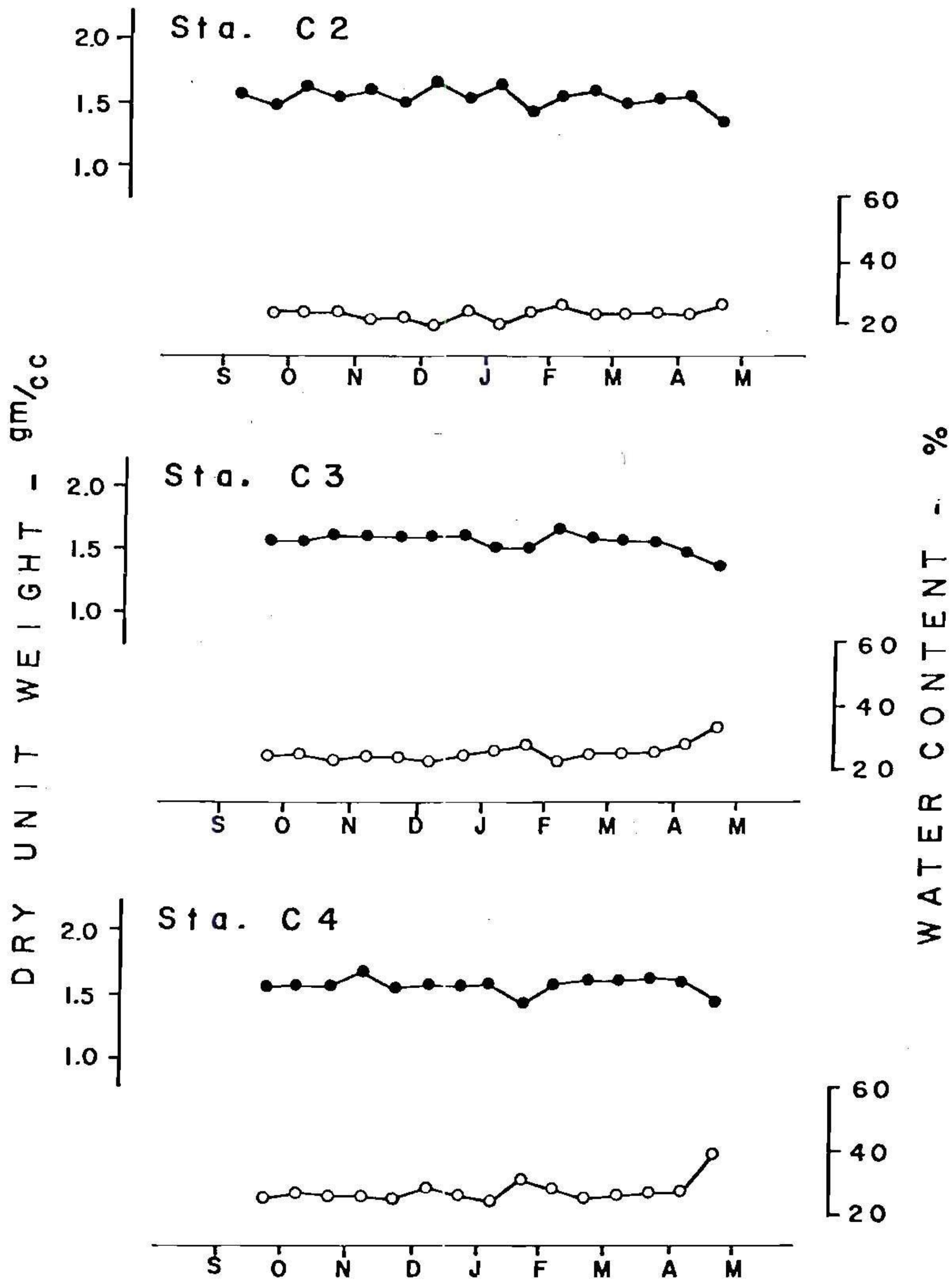

Figure 33. Relationship Between Unit Weight (•) and Water Content (°); Transect C

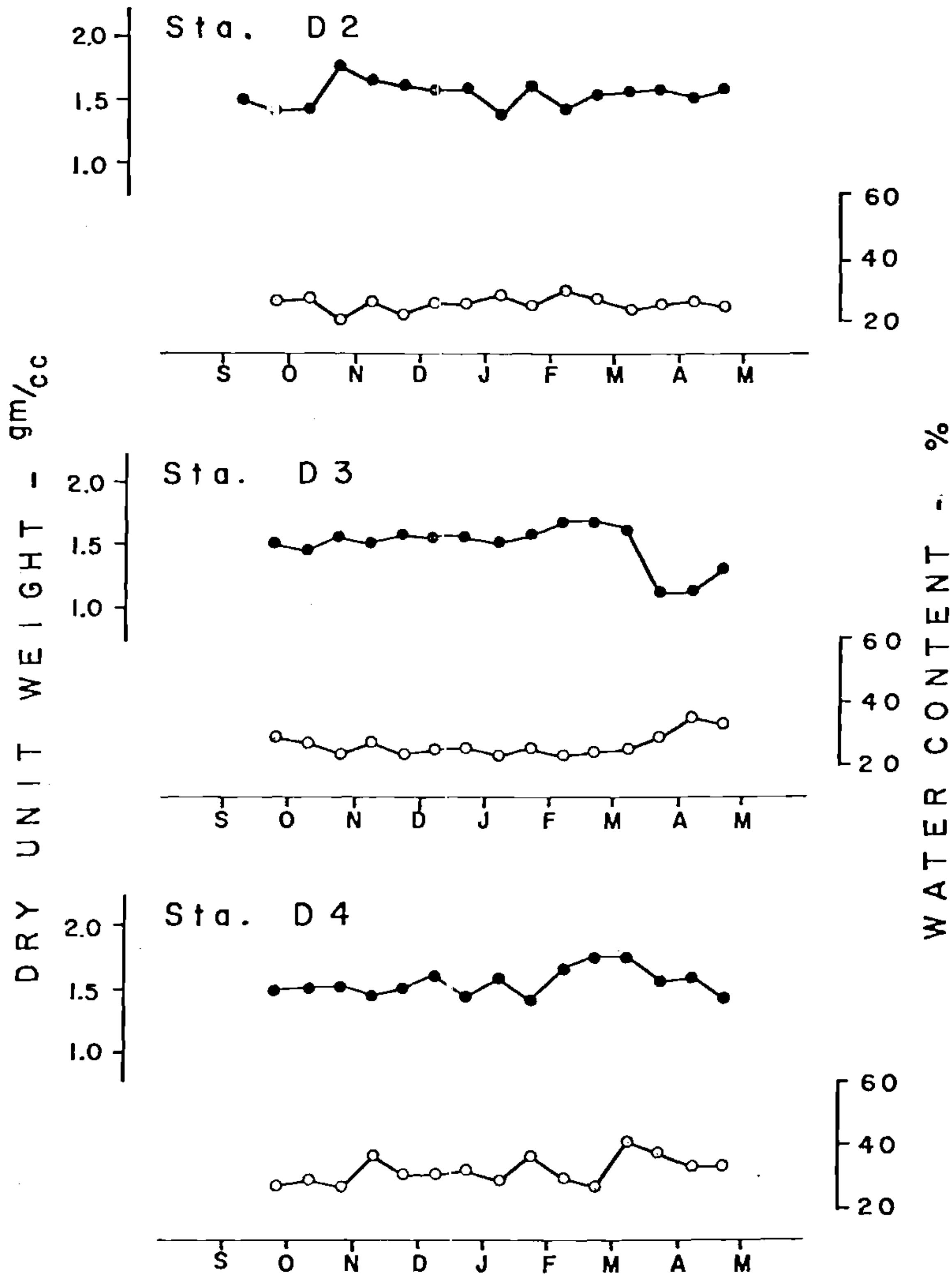

Figure 34. Relationship Between Unit Weight (•) and Water Content (o); Transect D

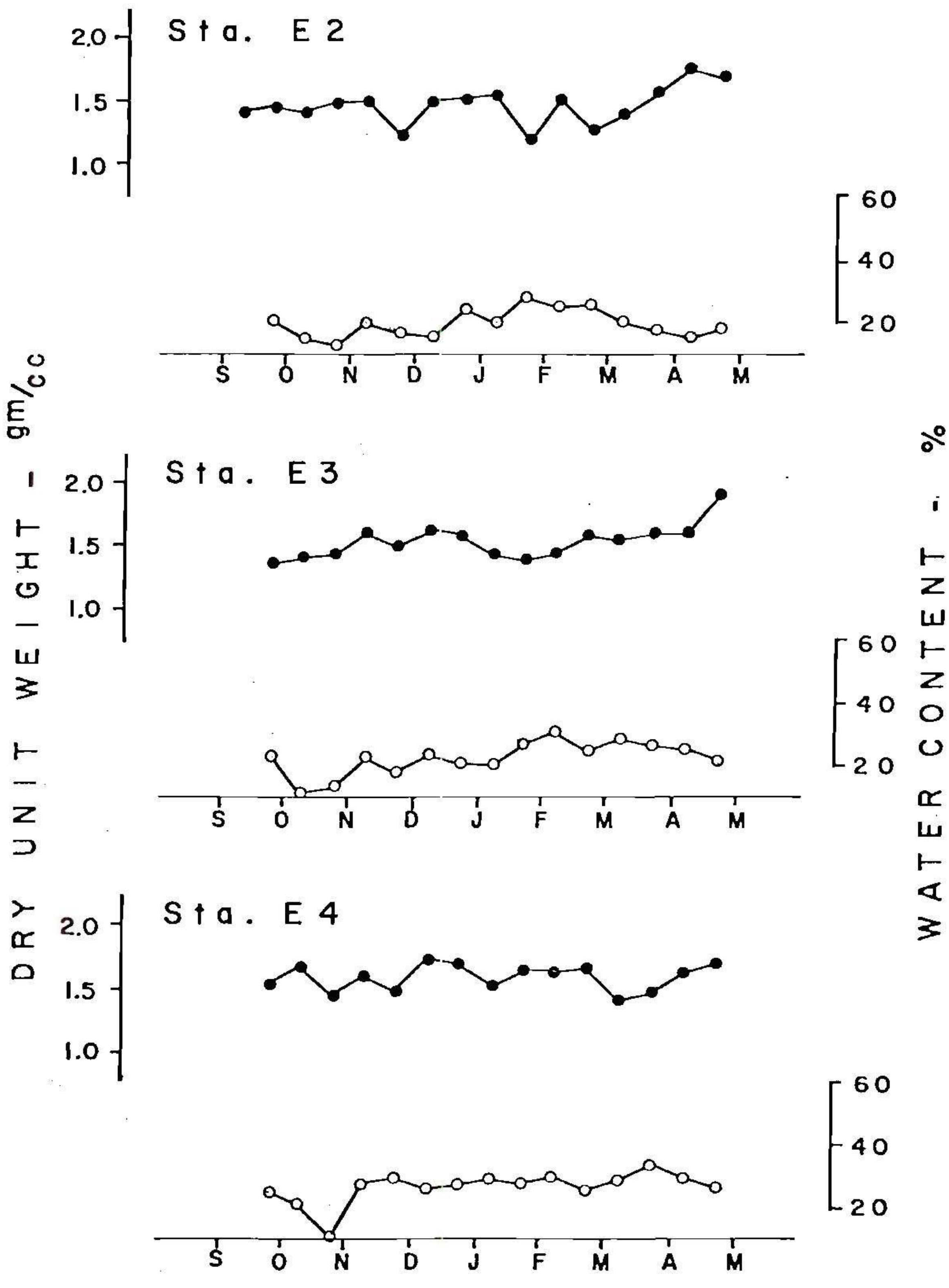

Figure 35. Relationship Between Unit Weight (•) and Water Content (o); Transect E

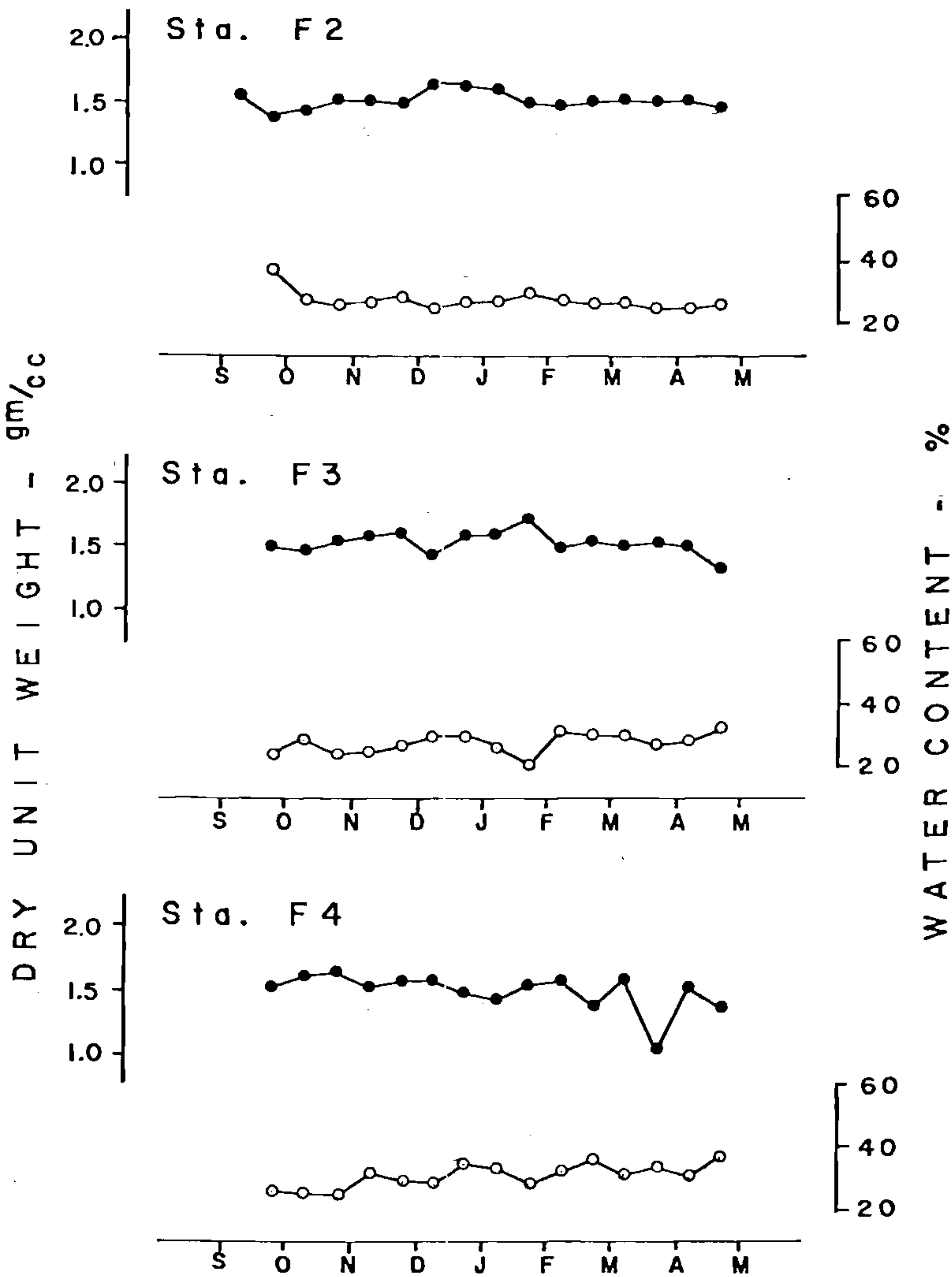

Figure 36. Relationship Between Unit Weight (•) and Water Content (o); Transect F

Table 7. Related Engineering Properties

Transect/Station		Average Shear Strength (g/cm^2)		Average Dry Unit Wt. (g/cc)		Average Water Content (%)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A	2	58.1	.10	1.41	.12	31.6	.04
	3	49.7	.11	1.51	.10	27.8	.04
	4	18.9	.12	1.43	.12	32.4	.22
B	2	80.6	.26	1.53	.09	26.3	.05
	3	61.1	.13	1.62	.08	26.0	.01
	4	79.4	.08	1.53	.12	30.3	.05
C	2	79.3	.13	1.57	.08	24.2	.02
	3	52.7	.14	1.56	.01	25.8	.07
	4	34.5	.10	1.55	.01	27.6	.14
D	2	70.7	.19	1.57	.12	26.8	.07
	3	53.7	.10	1.49	.03	26.4	.12
	4	30.4	.09	1.53	.01	31.7	.20
E	2	115.0	.56	1.47	.16	20.6	.21
	3	56.8	.07	1.53	.15	22.0	.05
	4	45.1	.11	1.56	.12	25.9	.06
F	2	85.8	.17	1.55	.07	27.5	.04
	3	74.4	.19	1.53	.09	27.7	.03
	4	38.2	.10	1.48	.02	30.6	.14

those of station 3. The dense vegetal root mass of the Spartina within the tires maintained a high water content and thus a low density, similar to what was found closer to the marsh center. Sediment from within the tires of the inclined revetment yielded the highest mean unit-weights of transects C and D. Although Spartina existed at these stations, its growth was less dense. With a minimal root system, less water was retained (Table 7), sediment was more tightly packed, and yielded increased unit-weight values. Dry-unit-weight values for the vertical revetment (transects E and F) illustrated no distinct variations. Sediment in this section was subjected to normal conditions of the marsh and unit-weight values responded primarily to water content.

Water Content

Following inundation sediment retained water by capillary forces produced through surface tension and physio-chemical bonds between water and soil. Many variables affected the actual degree of water content in sediments. Sowers and Sowers (1970) discussed in detail the role grain size and clay mineral assemblages play in water retention.

Pferd (1970) suggested that a direct correlation exists between water content and clay-organic matter content. He obtained highest water content values from organic rich and clayey samples of marsh.

Much work has been done on animal-sediment relationships (Howard and Frey, 1975; Myers, 1977; Rhoads and Young, 1970; Sanders, 1958). Rhoads and Young (1970) reported that high water content increased with the intensity of burrowing in sediments.

Other factors that may affect sediment water content are: duration between inundations, temperature, vegetation type and density, and marsh elevation.

Water content of each station varied little during the sampling period (Figs. 31 to 36). Biweekly water content values, listed in Appendix B, ranged from 8.3 percent to 43.8 percent. Pferd (1970) reported water contents of 26.8 to 74.6 percent and Teal and Kaniwasher (1961) also reported slightly higher values (50 to 70%).

Station 4, closest to the water's edge, yielded the highest mean water content to each transect (Table 7). Sediment from within the tires (station 2) of transects A, B and D produced a higher mean water content than station 3. These areas generally had smaller mean grain sizes and increased water content.

Sediment channelward of the vertical revetment, drained under normal conditions, and flow was not impeded and trapped in sediment. Therefore, as expected, the mean water content decreased landward along transects E and F.

Shear Strength

Shear strength is a basic parameter of soil and sediment engineering investigations. In essence, it provides a strength characteristic of the soil. For sands and coarse silts, shear strength is gained through internal friction and for finer silts and clays through cohesion. Further reviews of shear strength are covered by Lambe (1951) and Sowers and Sowers (1970).

Shear strength for this study was measured from *in situ* vane tests. Individual values were listed in Appendix C and ranged from

0.0 gm/cm^2 at station A4, to 247.0 gm/cm^2 at station E2.

Mean values obtained (Table 7) were comparable to those obtained by Pferd (1970) in corresponding marsh environments. With the exception of transect B, station 2 of each transect has the highest mean shear strength value (Table 7). Sediment strength decreased progressively away from station 2 and toward the marsh center. Station 4 of transect B had an anomalously high shear strength (79.4 gm/cm^2). The higher shear strengths may be attributed to the dense root mat of Spartina alterniflora.

The relatively low shear strengths for station 4 of the other transects (18.9 - 45.1 gm/cm^2) can be attributed to a high sediment-water content and a looser root system of the marsh-grass. This portion of marsh remained wetted throughout much of the tidal cycle and had a poorly developed, highly organic substrate. The increased strength of station 3 of all transects (49.7 - 74.4 gm/cm^2) resulted from better drainage qualities and thus, a lower water content. The sediment also contained a higher percentage of sand-size material (Table 5). A substantial sand fraction and low water content increased friction between grains and produced a higher shear strength. Highest shear strength values were reported in stations 2. Within the tires of the inclined revetment/mat and inclined revetment the Spartina root-system strengthened the internal structure of the sediment. The roots bound individual particles together, confined grain movement and thus increased the shear strength. Adjacent to the vertical revetment high shear strength values of stations 2 were produced by well-developed drainage and high internal friction. Strength values (Table 7) along station 2 of each transect illustrate that the tires produced an overall lowering in shear strength (58.1 gm/cm^2 - 80.6 gm/cm^2) as compared to freely drained sediments (85.8 - 115.0). The highest shear strength, 115.0 gm/cm^2, corresponded to the lowest water content, 20.6 percent and the lowest strength 18.9 gm/cm^2 to the highest water content 32.4 gm/cm^2.

Mineral Nutrient Results

The marsh grass Spartina alterniflora exhibited marked growth height differentials within the study site. Lush stands of Spartina a. near the marsh levee decreased in height and productivity toward the bank. Teal (1962) and Cooper (1974) identified three individual height forms of Spartina, tall, medium and short. Several workers believed the differences in height result from genetically different forms (Chapman, 1969; Stalter and Batson, 1969). However, investigations on the influence of environmental factors are yet inconclusive (Adams, 1963; Stalter and Batson, 1969).

Work by Broome et al. (1973) showed a positive correlation of Na, Fe, N, P, and Mn to growth height. Valiela and Teal (1974) also associated Spartina height with mineral nutrition of the soil. Using urea and phosphate fertilizers, they obtained a direct relationship between nitrogen and increased standing crops. They concluded that the abundance of phosphate already present in the sediments limited the effect on growth of additional phosphate. It was further suggested by Valiela and Teal that sediment and microflora remove substantial amounts of dissolved nutrients (particularly nitrogen) from the estuarine water.

The pH, organic matter (percent by weight) and concentrations of P, K, Ca, Mg, NO_3 and Na were monitored monthly for stations 2 and 3 and 4 of transect A (Table 8). The pH values ranged from 6.0 to 7.8. Phledger and Bradshaw (1965) report pH variations from 6.9 to 8.3 during a 24-hour period at Mission Bay, California. Relative concentrations of the mineral nutrients compared well with those obtained by Terry _et al_. (1974) in their study on marsh restoration at Hempstead, Long Island.

Increases in K and Mg within the tires suggested that these nutrients may accelerate _Spartina_ growth. Although phosphate also increased, it apparently had little influence on growth height (Pomeroy _et al_., 1969).

It is visually obvious that some anomalous parameter encourages superior standing crop productivity within the tires. To fully understand the relationship or cause and effect between sediment and halophyte requires more controlled experimentation. The fact remains that at this site the tire revetments promoted a lush healthy crop of _Spartina alterniflora_.

Table 8. Soil Analysis

Date	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	NO_3 (ppm)	Na (ppm)	Organic Matter %
				Station A 2				
11/77	6.6	24	71.5	406.5	157.5	5	80.0	—
12/77	6.7	26	87.0	336.5	180.5	5	975.0	.74
1/78	7.2	22	51.5	208.0	44.0	7	70.0	.40
2/78	7.8	24	41.5	237.5	70.0	2	—	.30
3/78	7.7	26	58.2	225.0	150.0	2	1156.0	.40
4/78	7.1	34	102.5	216.5	180.5	2	1296.0	.30
				Station A 3				
11/77	6.6	18	34.5	179.5	62.5	8.5	80.0	—
12/77	7.1	18	61.5	243.5	106.0	5	1562.5	.47
1/78	7.2	18	48.0	133.0	56.0	2	829.0	.30
2/78	6.9	18	35.0	191.0	38.5	3.5	—	.30
3/78	6.7	20	42.0	201.0	63.0	5	625.5	.40
4/78	6.3	22	78.0	219.0	140.0	2	755.0	.20
				Station A 4				
11/77	—	18	105.5	552.5	180.5	—	30.5	—
12/77	6.0	30	130.5	420.0	180.5	5	1562.5	.87
1/78	6.5	22	115.0	312.0	180.5	3.5	117.5	.50
2/78	6.8	16	88.0	183.5	111.0	2	—	.50
3/78	6.9	20	105.0	250.5	125.0	3	115.0	.60
4/78	7.1	32	129.0	272.0	180.5	4	115.2	.30

CHAPTER IV

CONCLUSIONS

The following conclusions are based on results obtained from the shoreline erosion study of the Atlantic Intracoastal Waterway of Georgia, performed between June 1977 and May 1978.

Field investigations of the shoreline indicate that:

(1) Active erosion of estuarine shorelines can be identified by physical features produced by erosional processes. Scarp height, marsh terrace form and bank face geometry assume characteristics unique to the erosional process effecting them.

(2) Approximately 34 percent of the 298 km of shoreline examined is actively eroding. Tidal scour and boat-generated waves are the central forces causing this erosion.

(3) Grass marsh and sand banks are the two predominant shoreline types in the study area. Whereas sand banks are all undergoing erosion, the marsh may be classified in one of several morphological states: eroding, stable or accreting.

(4) Treated wood bulkheads and stone/rubble revetments are the principal structures employed for erosion control on the A.I.W.W.

(5) Excessive cost of professionally engineered structures often prompts use of poorly designed and ineffective methods

of erosion control.

Geotechnical evaluation of three scrap-tire revetment designs concludes that:

(1) All three revetment designs successfully halted wave erosion of the Pleistocene bank.

(2) The marsh surface-sediments showed only slight variations in their engineering properties following the revetment installation. The revetments protect the bank but do not detrimentally alter the internal structure of the marsh substrate.

(3) Tire mats placed on the fringe of a Spartina marsh will promote rapid, lush growth of the grass. Inclined revetments with such a mat are best suited for areas that are lacking substantial marsh vegetation and/or where daily mid to MHW produces substantial tidal scour on the fore-marsh slope and wave attack to the bank face (typically, sand banks, vertical or undercut, that lack any primary marsh protection).

(4) Inclined revetments, minus the mat, are applicable for shores that sustain an adequate standing marsh-grass crop and do not require increased growth and/or are subject to wave attack at Spring tides (i.e., protection of an eroding grass marsh or an undercut sand bank fronted by either a stable or eroding grass marsh.

(5) Vertical revetments provide protection to banks already fronted by a densely vegetated marsh terrace but are subjected to attack only during high storm surges (i.e., vertical and undercut sand banks fronted by a stable grass marsh.

(6) Scrap-tire revetments provide a low-cost, easily constructed method of erosion control that may replace coventional structures which are more costly. The ability to adapt several basic designs of scrap tire revetments to a variety of environments allows for a widespread application of their use.

APPENDIX A

INDIVIDUAL DRY UNIT WEIGHT (g/cc)

	Date of Sample															
	1977							1978								
Station	9/12	9/21	10/10	10/20	11/16	11/20	12/6	12/19	1/11	1/26	2/8	2/21	3/7	3/22	4/5	4/20
	Transect A															
2	1.45	1.43	1.36	1.50	1.44	1.24	1.45	1.27	1.28	1.19	1.57	1.61	1.36	1.48	1.48	1.50
3		1.52	1.62	1.51	1.50	1.52	1.53	1.43	1.55	1.52	1.24	1.66	1.59	1.57	1.59	1.39
4		1.52	1.36	1.52	1.25	1.53	1.44	1.55	1.48	1.33	1.50	1.53	1.42	1.48	1.45	1.11
	Transect B															
2	1.36	1.47	1.45	1.59	1.58	1.55	1.58	1.57	1.51	1.56	1.59	1.58	1.55	1.60	1.60	1.33
3		1.57	1.52	1.67	1.56	1.56	1.60	1.58	1.54	1.52	1.73	1.76	1.63	1.73	1.71	1.58
4		1.39	1.60	1.52	1.46	1.44	1.31	1.54	1.35	1.70	1.54	1.73	1.60	1.56	1.59	1.62
	Transect C															
2	1.61	1.49	1.67	1.57	1.65	1.53	1.64	1.57	1.68	1.48	1.59	1.64	1.53	1.56	1.58	1.38
3		1.56	1.56	1.61	1.61	1.61	1.62	1.61	1.51	1.50	1.67	1.60	1.58	1.55	1.49	1.33
4		1.56	1.56	1.56	1.67	1.53	1.55	1.56	1.55	1.42	1.55	1.58	1.59	1.60	1.57	1.41
	Transect D															
2	1.54	1.41	1.47	1.78	1.67	1.63	1.61	1.62	1.35	1.66	1.47	1.52	1.59	1.59	1.55	1.60
3		1.49	1.46	1.57	1.53	1.58	1.57	1.56	1.50	1.58	1.69	1.67	1.62	1.12	1.14	1.31
4		1.48	1.50	1.53	1.44	1.49	1.58	1.42	1.55	1.39	1.65	1.76	1.73	1.55	1.55	1.39
	Transect E															
2	1.43	1.45	1.42	1.47	1.52	1.24	1.51	1.54	1.56	1.16	1.54	1.26	1.43	1.59	1.77	1.70
3		1.35	1.39	1.42	1.60	1.48	1.66	1.61	1.43	1.38	1.43	1.56	1.54	1.57	1.58	1.97
4		1.50	1.63	1.40	1.58	1.45	1.72	1.67	1.48	1.64	1.62	1.63	1.38	1.46	1.60	1.67
	Transect F															
2	1.60	1.43	1.47	1.56	1.51	1.54	1.68	1.67	1.65	1.52	1.52	1.54	1.56	1.54	1.54	1.48
3		1.52	1.47	1.56	1.59	1.62	1.44	1.57	1.58	1.74	1.49	1.54	1.49	1.54	1.51	1.33
4		1.51	1.61	1.62	1.52	1.56	1.57	1.46	1.41	1.52	1.56	1.37	1.56	1.02	1.50	1.34

APPENDIX B

INDIVIDUAL WATER CONTENT (%)

	Date of Sample														
	1977										1978				
Station	9/21	10/10	10/20	11/16	11/20	12/6	12/19	1/11	1/26	2/8	2/21	3/7	3/22	4/5	4/20
								Transect A							
2	29.5	29.7	29.6	28.4	28.7	30.6	37.7	31.6	35.3	32.1	30.5	42.3	27.1	30.1	30.2
3	26.1	25.6	25.9	25.2	25.3	24.5	34.6	31.7	23.3	39.3	28.4	26.6	25.9	25.1	29.2
4	30.0	34.6	27.0	34.0	27.6	34.9	27.2	30.5	43.8	28.7	29.9	33.4	32.2	32.5	40.2
								Transect B							
2	27.3	27.4	24.5	25.8	24.6	26.7	25.3	25.5	27.0	24.3	24.8	25.4	27.4	25.2	33.4
3	24.5	25.8	24.4	24.4	24.5	27.7	28.0	28.9	25.2	26.9	25.3	26.6	25.2	25.1	27.0
4	28.2	25.3	27.2	26.0	29.8	38.2	35.2	37.6	20.3	36.1	32.7	31.4	30.5	28.4	27.1
								Transect C							
2	24.8	24.5	24.3	22.6	23.4	21.1	25.6	21.8	25.0	27.5	24.0	24.7	24.9	24.5	27.9
3	24.7	25.4	23.8	24.8	24.1	23.8	24.6	26.2	28.0	23.8	24.9	25.2	25.7	28.3	34.0
4	25.6	26.7	26.0	26.0	25.5	28.7	25.9	24.4	31.3	28.5	25.2	26.3	27.3	27.1	39.8
								Transect D							
2	28.0	28.7	21.2	27.3	23.0	27.3	27.4	29.7	26.2	31.6	28.6	24.4	26.5	27.6	25.1
3	28.2	27.4	22.9	26.4	23.8	25.3	25.4	23.2	25.4	23.1	24.0	25.6	28.1	35.1	32.1
4	27.5	28.5	26.7	36.3	30.7	30.5	31.2	28.8	36.3	29.4	26.1	41.9	37.3	32.9	32.0
								Transect E							
2	21.8	15.8	13.7	20.5	17.1	16.2	25.9	20.5	28.6	26.0	26.5	21.9	18.6	16.0	19.2
3	22.1	10.6	12.5	22.1	17.1	22.9	20.5	20.7	26.3	30.2	24.3	28.5	26.5	25.0	21.3
4	24.2	20.6	8.4	26.9	28.7	25.7	26.6	28.5	27.3	28.7	25.8	27.9	33.7	28.5	26.2
								Transect F							
2	39.7	27.8	26.1	27.0	28.7	25.1	26.3	26.6	29.1	27.8	25.9	26.0	25.0	24.9	26.0
3	24.6	29.1	24.5	25.2	26.7	29.3	29.3	26.6	21.8	31.3	29.3	29.7	27.7	28.3	32.4
4	25.8	25.2	24.8	31.0	29.0	28.3	34.4	32.9	28.0	32.4	35.8	30.2	33.5	30.9	36.1

APPENDIX C

INDIVIDUAL SHEAR STRENGTH (g/cm^2)

	Date of Sample															
	1977											1978				
Station	9/12	9/21	10/10	10/20	11/16	11/20	12/6	12/19	1/11	1/26	2/8	2/21	3/7	3/22	4/5	4/20
	Transect A															
2	45.0	53.3	75.0	53.0	60.0	60.0	68 2	51.3	69.1	70.0	50.0	55.0	44.2	75.0	52.1	50.3
3		52.1	50.0	51.0	53.0	70.0	72 0	42.0	48.1	54.0	33.0	30.0	44.2	48.0	51.0	47.1
4		31.0	9.1	12.0	7.0	0.0	10 0	26.3	22.0	0.0	28.3	31.0	25.0	32.0	31.8	19.0
	Transect B															
2	38.3	46.7	113.3	93.3	90.0	53.0	72.1	81.9	72.0	75.0	82.3	145.0	63.3	82.0	93.0	89.2
3		63.0	72.1	73.0	83.0	70.0	63.1	71.0	68.0	51.0	59.2	38.0	47.5	53.5	61.0	42.0
4		72.0	85.1	86.0	—	70.0	73.0	69.0	72.5	94.0	87.1	88.0	83.8	73.2	75.0	82.0
	Transect C															
2	87.0	63.3	100.0	93.3	100.0	67.0	75.0	82.1	80.0	78.5	77.0	66.3	55.0	72.1	89.0	82.7
3		63.0	62.1	53.0	50.0	63.0	64.0	63.3	65.0	52.0	65.0	13.8	38.3	46.0	52.2	41.0
4		32.0	46.1	39.0	20.0	43.0	45.2	39.0	37.0	31.0	36.0	38.8	38.3	32.0	35.0	5.0
	Transect D															
2	95.0	66.7	110.0	110.0	47.0	70.0	65.1	72.0	73.8	69.0	63.0	60.8	46.7	61.0	58.2	63.0
3		42.1	53.0	55.0	50.0	73.0	63.1	65.0	63.0	59.2	60.0	54.2	44.2	42.0	43.1	39.0
4		41.0	34.0	33.8	29.2	37.0	33.0	30.0	32.8	23.0	32.0	30.3	2.0	31.5	36.0	30.0
	Transect E															
2	152.1	150.0	171.7	247.0	216.7	67.0	91 0	83.1	81.0	92.2	85.0	91.7	44.2	92.0	89.1	87.0
3		53.0	72.0	64.2	53.0	53.0	59 2	57.1	56.0	57.0	48.0	50.0	45.0	61.0	59.2	65.0
4		43.0	51.2	49.0	50.0	50.0	38.0	42.1	36.5	33.0	40.0	75.8	35.0	31.5	51.3	49.8
	Transect F															
2	82.9	86.7	133.3	110.0	97.0	60.0	81.2	82.0	82.0	85.0	86.1	88.8	60.0	83.0	75.1	79.0
3		75.0	82.1	63.0	120.0	80.0	82.3	79.0	81.0	97.0	68.2	—	53.0	56.0	53.5	51.1
4		36.7	41.0	29.0	20.0	46.7	31.0	33.5	45.0	44.0	40.5	—	56.3	38.6	35.0	36.0

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A Shoreline Erosion Study

of the Atlantic Intracoastal Waterway of Georgia,

Classification and Methods of Erosion Control

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80 Pages

Directed by Dr. G. F. Oertel

The Atlantic Intracoastal Waterway (A.I.W.W.) of Georgia is bordered by approximately 370 km of shoreline. Erosion occurs along much of the Waterway as tidal scour and boat-generated waves persistently attack the shores. As development of estuarine shoreline property increases, the need for a better understanding of estuarine erosion and its control is apparent. To date, research on shoreline erosion within the vast estuarine system of Georgia has been limited.

A qualitative study was conducted on approximately 290 km of the A.I.W.W. of Georgia. The purpose of this study was to develop a systematic classification of shoreline erosion types prevailing on the A.I.W.W. of Georgia and to discuss mechanisms of erosion control. Investigations were limited to those portions of the Waterway located behind the protective barrier islands, excluding that portion of the route which passes through the sounds. Characteristic features produced by erosional processes were used to locate areas of active erosion and aided in the classification of shoreline types along the Waterway.

Field observations indicate that approximately 34 percent of the investigated shoreline is undergoing active erosion. It was also found that two types of shoreline exist: 1) grass marshes which are either eroding, accreting or stable, depending on their morphological status, and 2) sand and clay banks which are eroding and forming vertical, undercut faces.

A wide variety of erosion control structures are in use on the A.I.W.W. The most common commercial structures employed are treated wood bulkheads and stone revetments. The high cost of these structures often prohibit their use and alternative "home-made" devices are attepmted, most of which were poorly designed and improperly constructed.

An alternative low cost erosion control system was installed on the A.I.W.W. and monitored from June 1977 to May 1978. The system consisted of three scrap tire revetment designs. Geotechnical examination of the surrounding marsh sediment was made on a regular basis to determine what effect the structures had on the marsh substrate and how effective they were in protecting an adjoining Pleistocene sand bank. Shear strength, water content, dry unit weight and size analysis of the sediments showed only slight variations throughout the study. The revetments had no apparent detrimental effect on the marsh substrate and presumably did not disrupt natural ecological processes. Further monitoring demonstrated that the three revetment designs tested successfully halted the erosion of the sand bank.

One section of revetment was fronted by a tire mat extending to the fringe of the *Spartina* marsh. Within three months following construction, the _Spartina_ rapidly populated the tire mat and grew to heights nearly triple that of the grass anterior of the mat. Initial investigation of the sediment revealed increased levels of K and Mg within the tire mat.